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TTEB PROGRAMME DE TRANSFERT DE LA TECHNOLOGIE DE L'ENERGIE DANS LES BATIMENTS

# Testing of Air Leakage and Combustion Efficiency in Rooftop HVAC Units

## A RESEARCH REPORT

Canada

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# Testing of Air Leakage and Combustion Efficiency in Rooftop HVAC Units

## A RESEARCH REPORT

Field Test of 51 Rooftop Units

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## ABSTRACT/RESUME

Field tests were conducted on 51 building HVAC rooftop units. Each field test examined general rooftop condition, control methods, combustion efficiency and outside air leakage. Outside air leakage was defined as the outside air volume supplied to floor space with the rooftop unit in the heating mode and the supply fan operational.

Test results showed that most rooftop HVAC units were poorly maintained. Approximately 50% of all units tested showed excessive outside air volumes. Combustion efficiency tests for gas-fired rooftop units showed potential for improvement in one third of all units tested.

* * *

On a soumis à des essais sur le terrain 51 systèmes CVC sur toit. On a chaque fois examiné l'état général de la toiture, les méthodes de contrôle, l'efficacité de la combustion etl'infiltration d'air extérieur. En l'occurrence, en entend par infiltration d'air le volume d'air extérieur qui entre dans la maison pendant que le système est en mode de chauffage et que le ventilateur fonctionne.

Les essais on démontré que la plupart des systèmes CVC sur toit n'étaient pas bien entretenus. En effet, près de 50 % de tous les systèmes admettaient une quantité excessive d'air extérieur. Par ailleurs, les essais démontrent que l'efficacité de la combustion pour les systèmes au gaz pourrait être améliorée dans un tiers des cas.

Le lecteur trouvera un sommaire du prèsent rapport, en français, á la page i.

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La présente étude est une synthèse des résultats d'essais sur le terrain auxquels on a soumis 51 systèmes CVC sur toit dans le sud de l'Ontario.

L'étude visait principalement les objectifs suivants :

1. Mesurer l'infiltration totale d'air extérieur.

2. Mesurer l'efficacité de la combustion de tous les systèmes à combustible.

3. Recueillir des données pertinentes sur l'état et le fonctionnement de chaque système.

4. Compiler les données recueillies et formuler des recommandations pour accroître l'efficacité des systèmes CVC sur toit.

Les données recueillies révèlent que le pourcentage moyen d'air extérieur représente 8,4 % du taux d'approvisionnement en air pour un système qui n'est pas muni d'un économiseur, tandis que ce pourcentage est de 13,9 % quand le système en est doté. Le pourcentage d'air extérieur varie surtout en fonction du registre d'admission d'air extérieur de son réglage. Ce pourcentage est excessif et peut être réduit dans la moitié des cas.

Le taux d'efficacité de la combustion des systèmes au gaz s'établit en moyenne à 69 % et peut être amélioré dans au moins un tiers des cas.

Les systèmes sur toit sont en général très mal entretenus. Le filtre principal de la plupart des systèmes équipant les petits magasins se révèle être dans un état passable ou carrément mauvais. L'étude démontre également que l'infiltration peut être réduite si l'on abaisse la température pendant la nuit.

La méthode d'essai décrite dans le présent rapport peut servir aux propriétaires pour déterminer si leur système fonctionne bien. Les essais permettant de mesurer l'efficacité de la combustion peuvent être effectués par un entrepreneur.

Pour accroître l'efficacité des systèmes CVC sur toit, le rapport formule les recommandations suivantes :

1. Maintenance et mise au point périodiques.

2. Installation d'un thermostat programmable.

3. Préparation d'un guide décrivant le fonctionnement et la maintenance des systèmes CVC sur toit pour que les propriétaires puissent en obtenir un rendement optimal.

The rooftop HVAC* unit has become the dominant package for providing space conditioning in retail buildings and small commercial/industrial buildings. The popularity of rooftop units can be attributed to two factors:

1. Units do not occupy floor space.

2. Units are mass produced for low capital cost.

At the time of writing of this report, a rough estimate was made of the rooftop HVAC unit population in Canada. A subsequent BETT report** provided a considerably more accurate picture of the actual number of units in service (as of 1984) across the country. Only the numbers provided in the subsequent report are reproduced here.

Using statistics provided by the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAIC) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), the subsequent report estimates the total Canadian rooftop HVAC unit population to be 160,000 units.

The present survey of 51 rooftop HVAC units showed that the average unit surveyed provided conditioning for 217 $m^2$ of floor area. Multiplying this figure by the 160,000 units in service provides an estimate of 35,000,000 $m^2$ of floor space served by rooftop units for the whole of Canada.

* HVAC--Heating, Ventilating and Air Conditioning

** BETT Research Report, Energy Efficient Control, Retrofit and Selection of Rooftop HVAC Units, December 1985, (Unpublished) (OR. 84-11).

The operational efficiency of rooftop HVAC units directly affects the energy consumption of about 35,000,000 $m^2$ of floor space in Canada. This study is designed to investigate the efficiency of rooftop unit operation and to suggest strategies for more efficient operation.

## 2.0 OBJECTIVES

The objectives of this study are to:

1. Conduct field tests for 51 rooftop units.
2. Measure outside air leakage of each unit.
3. Measure combustion efficiency of fuel fired units.
4. Collect information concerning the maintenance and operation of each rooftop unit.
5. Make recommendations for improving operating efficiency and reducing energy consumption.

## 3.0 TEST METHODOLOGY

A sample of 51 rooftop units was selected for detailed testing. Selection of the test sample was based on several criteria:

1. Age of units
2. Manufacturer of unit
3. Air economiser cycle (yes or no)
4. Type of heating fuel
5. Size of unit.

All units tested were located in Southern Ontario.

The data collection form or questionnaire is shown on page 5 . A listing of significant data captured for each test is summarized below:

Manufacturer of Unit
Age of Unit
Floor Area Served
Outside Air Damper Area
Condition of Unit
Economiser Option (Yes/No)
Type of Heating Fuel
Thermostat Setting for Unit Operation
Type of Control for Unit
Combustion Efficiency of Fuel-Fired Units
Temperature of Flue Gas
Oxygen Concentration in Flue Gas
Supply Air Volume of Unit
Ambient Temperature During Leakage Test
Return Air Temperature During Leakage Test
Supply Air Temperature During Leakage Test.

Each field test can be divided into three operations:

1. General Inspection
2. Leakage Test
3. Combustion Test

## ROOFTOP UNITS STUDY

TEST NO _____ DATE _____
LOCATION _____ TIME _____
_____ WIND SPEED _____

**Rooftop Unit:**

MANUFACTURER _____
SERIAL NO. _____ AGE _____
FLOOR AREA SERVED _____
DAMPER AREA _____ = _____ * _____
DAMPER SETTINGS _____

**Unit Condition:** ( GOOD (G) , FAIR (F) , POOR (P) )
SHELL CONDITION _____ MAIN FILTER CONDITION _____
OUTSIDE AIR DAMPER CONDITION _____
OUTSIDE AIR SCREEN OR FILTER CONDITION _____
ACCESS PANELS SECURE (YES OR NO) _____
ECONOMIZER CYCLE (YES OR NO) _____
IF YES HIGH LIMIT SETTING _____ °F
MIXING TEMP SETPOINT _____ °F

**Type of Heating:**
GAS _____
OIL _____
ELECT. _____
BTU _____
kW. _____

**Cooling**
BTU _____
kW. _____

**Normal Control:**

THERMOSTAT SETTINGS: HEATING ____ °F
(CHECK X) COOLING ____ °F

- AUTOMATED CONTROL YES _____ NO _____
- MANUAL CONTROL YES _____ NO _____
- NIGHT SET BACK YES _____ NO _____
- TIME CLOCK YES _____ NO _____

SCHEDULE OF CONTROL _____
UNITS PER CONTROL POINT _____

**Combustion Test:**

COMBUSTION TEST READINGS:
① _____ % EFFY ② _____ % EFFY ③ _____ % EFFY
_____ °C ΔT _____ °C ΔT _____ °C ΔT
_____ % OXYGEN _____ % OXYGEN _____ % OXYGEN

**Leakage Test:**

AMBIENT TEMPERATURE _____ °F
RETURN AIR TEMPERATURE _____ °F
SUPPLY AIR TEMPERATURE _____ °F
SUPPLY AIR VOLUME _____ CFM

REMARKS: _____

## 3.0 TEST METHODOLOGY

All three operations are performed during the on-site visit.

### 3.1 General Inspection

A contact person is established for each site visit. The contact person is responsible for the control and operation of the rooftop HVAC unit in the building. For large retail stores, the contact person is typically a building operator with maintenance responsibility. For small stores, the contact person is typically the store manager or business owner.

The contact person provides information regarding the thermostat settings and type of control. Information provided by the contact person is checked against field test observations. Past performance of the rooftop HVAC unit is also discussed with the contact person.

The questionnaire information (except combustion and leakage test) is recorded during the general inspection. Specific information relating to the rooftop unit is recorded following a detailed visual inspection. The access panels are removed to gain access to filters and combustion headers.

### 3.2 Leakage Test

The leakage test is accomplished by taking four measurements: ambient air temperature, supply air temperature, return air temperature and supply air rate. The rooftop heating and cooling cycle must be disabled during this test.

The heating and cooling thermostat set points are altered to shut off heating and cooling. The rooftop fan is kept running by selecting the FAN-ON setting at the thermostat. Supply air volume is then measured in one of two ways:

## 3.0 TEST METHODOLOGY

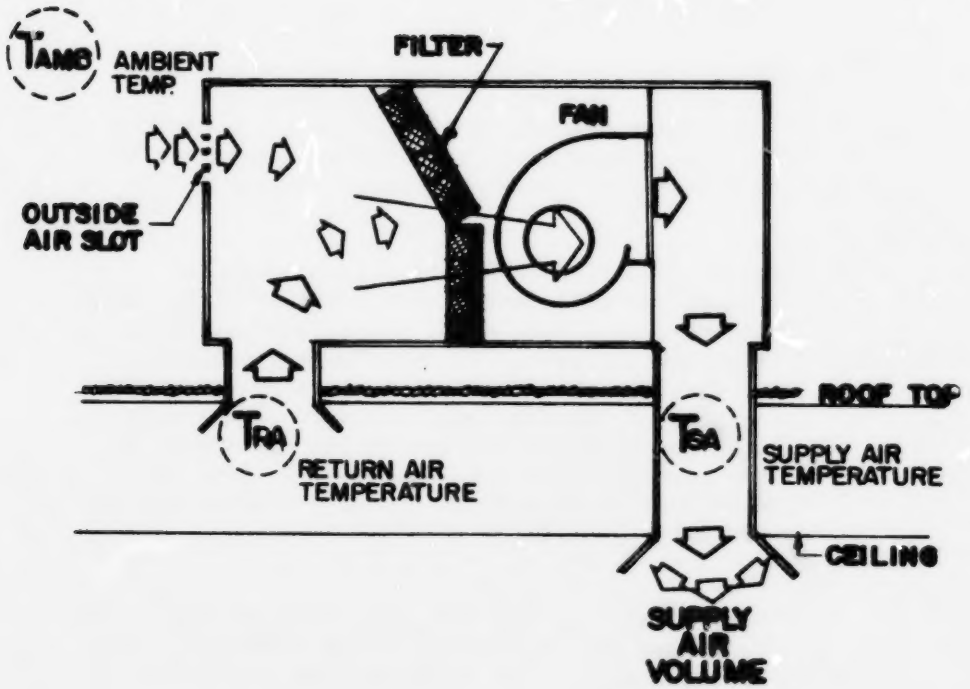
1. Providing a run of straight duct is available equal to 7 1/2 times the effective diameter of the duct cross section, a traverse of air velocity readings can be taken. Normally, a minimum of sixteen (16) velocity measurements are made for each test. Each velocity measurement corresponds to a specific cross section of the duct. Small holes are drilled in the duct to obtain the required measurements with a pitot tube.

2. Providing no long straight run of supply duct is available, the velocity measurements must take place at the diffusers. Velocity measurements are taken at each face of the diffuser. The results are averaged and a conversion factor is used for the diffuser type in order to calculate diffuser airflow rate. All supply air diffusers are measured and summed to give total supply airflow rate.

## 3.0 TEST METHODOLOGY

Care must be taken to insure that no residual heat remains in the rooftop heat exchanger from previous heating cycles. Operation of the fan for ten (10) minutes without heating/cooling will insure that accurate temperature readings can be taken. Temperature readings must be taken together as a group: return air, supply air and ambient air temperature.

The diagram below illustrates these temperature readings taken for the leakage test.




**STANDARD ROOFTOP UNIT**
**Normal Operation-Test Measurement**

FIGURE 3.1

Outside air leakage is calculated by the following method:

$$\text{Outside Air \% of Supply Air} = \frac{(\text{Return Air Temp.} - \text{Supply Air Temp.}) \times 100}{(\text{Return Air Temp} - \text{Ambient Temp})}$$

$$\text{Outside Air Leakage} = \frac{\text{Outside Air \%} \times \text{Supply Airflow Rate}}{100}$$

Temperature readings for airflow are recorded using a good quality mercury thermometer. Thermometer accuracy is labelled as +/- 1/4°C.

## 3.3 Combustion Test

The combustion test is conducted for all fuel-fired rooftop units (oil or gas). Electric resistance heating rooftop units are subjected to the leakage test; efficiency is recorded as N/A (not applicable) for these units.

A device called an FEM is used to measure combustion efficiency. The FEM (Fuel Efficiency Monitor) is a hand held, completely automatic flue gas analyzer. It measures the temperature of flue gas above ambient temperature and oxygen content of the flue gas. This information is used to calculate the percentage efficiency of the combustion device. Appendix 2 shows an on-site test in progress. Appendix 3 describes the FEM meter in greater detail.

Preliminary testing with gas fired rooftop units confirmed the importance of FEM probe location during a test. The probe must be located as close as possible to the combustion chamber. A probe location near the exhaust port may result in dilution of flue gas with outside air. A small hole can be drilled in the exhaust manifold to insert the probe. Location of the probe in the exhaust manifold avoids the problem of outside air dilution. This procedure produced consistent readings in all field tests.

## 3.0 TEST METHODOLOGY

A minimum of three flue gas samples are taken for each combustion test. The sample readings will be almost identical if the test is taken properly. As shown on page 5, the questionnaire provides space for recording three independent samples.

The thermostat heating control in the building is reset to a much higher temperature than room temperature for the test. This procedure insures the rooftop HVAC unit will be active in the heating mode. The rooftop HVAC unit is allowed to warm up and reach a steady state condition before the combustion test begins. Warm-up period is usually about 5 minutes.

All rooftop tests are identified by a unique test number from 1 to 51. The majority of the questionnaire data was loaded into a relational database to facilitate data manipulation.

The relational database system INGRES was used in order to structure the listings in Tables 1 to 6. INGRES is a relational database management system available on the DEC VAX family of computers under the VMS operating system. INGRES was developed over the past six years, and is currently installed at more than 125 locations world-wide. INGRES, in addition to meeting all the requirements of the relational database model, allows its users to describe, create, modify, retrieve and delete data efficiently in an interactive environment. All modern database management ideas, such as separation of the logical structure of the database, management of data security, integrity and recovery functions are embodied in INGRES.

More information about INGRES can be found in Appendix 1.

## 4.1 Building Test Group

Buildings selected for the test were primarily retail stores. The type of store varied from a small self-contained building to large department stores. Several rooftop units tested serve industrial low rise buildings. Industrial building rooftop units do not differ from the retail building rooftop units.

The rooftop units tested are primarily gas-fired units. No oil-fired rooftop units are included in the sample. Oil-fired rooftop units are not prevalent in the Toronto area. Older retail buildings with oil-fired plants have heating plants located in the building interior.

## 4.0 TEST RESULTS

The combustion test is not applicable to the electric rooftop units in test numbers 3 and 4 respectively. A value of N/A is recorded for combustion test results in each case.

Leakage tests could not be conducted for test numbers 37, 38 and 39. The rooftop units required the supply fan and combustion cycle to be operated simultaneously. A value of N/A is recorded for leakage test results in each case.

## 5.0 TEST ANALYSIS

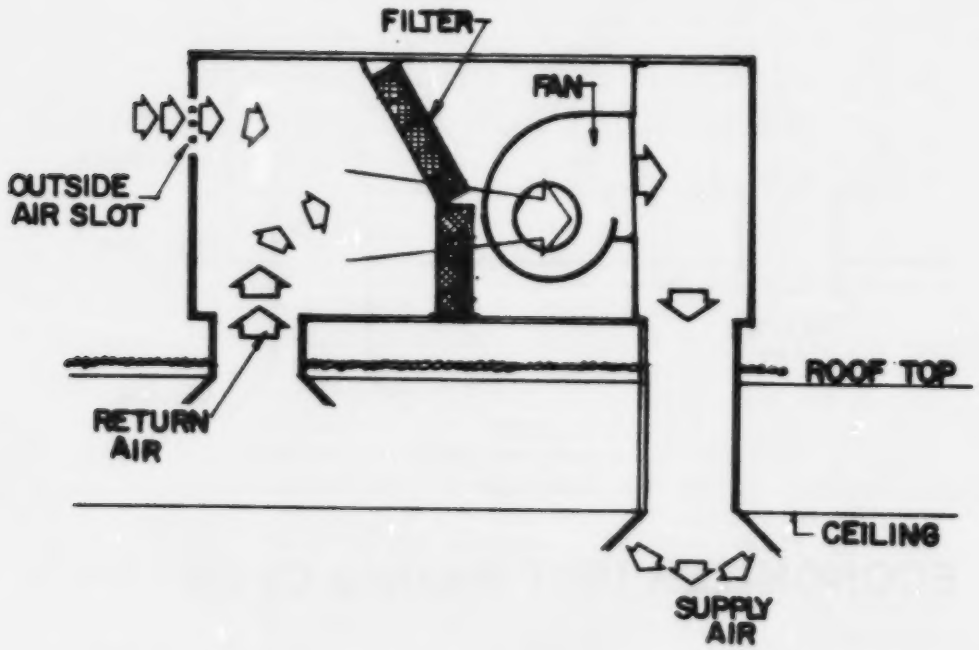
The analysis of test results is divided into three basic sections:

1. Outside air leakage and control
2. Combustion efficiency
3. Operation and Maintenance.

Test data was reviewed to explore trends and relationships affecting the operational efficiency of rooftop units. Significant relationships were identified and recommendations are made to improve rooftop operation.

### 5.1 Outside Air Leakage and Control

Rooftop units normally provide the capacity to mix outside air with return air. The outside air is sometimes referred to as "make-up air" or "fresh air" or "ventilation air". Typically a system may be designed to supply 10% outside air mixed with 90% return air. Operation of a typical unit is shown below:

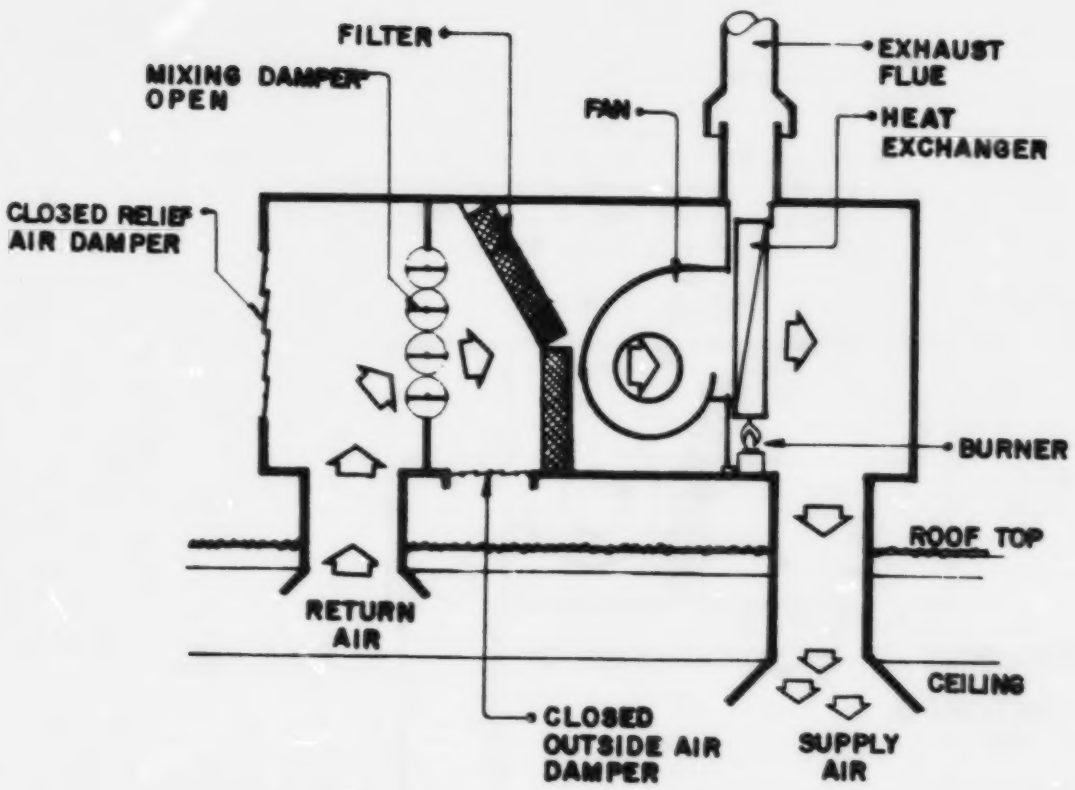



**STANDARD ROOFTOP UNIT**

FIGURE 5.1

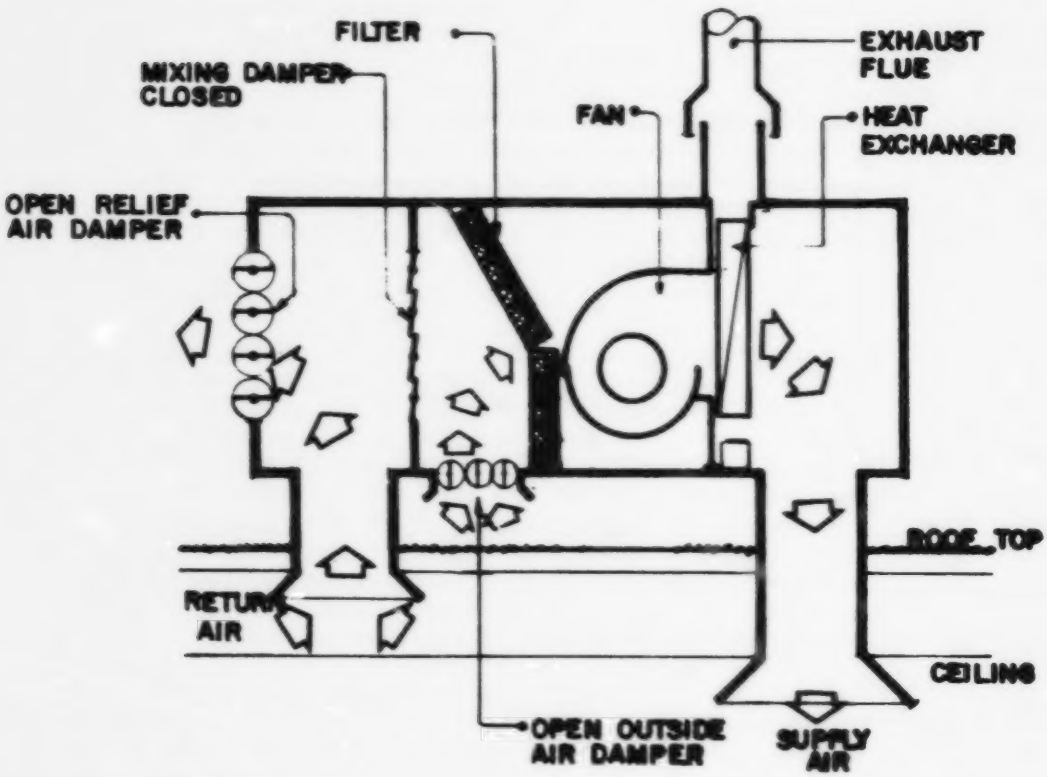
The outside air slot is adjustable in most units. The adjustment allows the quantity of outside air to be varied from 0% to a maximum of about 15%. The outside air adjustment is normally set by the installer and left untouched during the life of the unit.

Rooftop units equipped with air economiser cycles are designed to use outside air for cooling whenever possible. Outside air cooling is possible whenever ambient temperature is below room temperature. The economiser cycle adjusts the percentage of outside air supplied to the space. Excess return air is exhausted at the unit. Economiser cycle operation is diagramed below:




**ECONOMIZER UNIT Heating Cycle**

FIGURE 5.2




**ECONOMIZER UNIT**
**Cooling Operation Full Outside Air**

Figure 5.3

The test methodology described in Section 3 of this report is designed to measure the actual percentage of outside air in supply air. Outside air can be introduced in a controlled way through the outside air slot opening or the economiser damper opening. Outside air is also introduced through leakage in the rooftop shell or leakage around closed air dampers. Test results measure the total of controlled and uncontrolled leakage. The test result is referenced as outside air % in this report. Economiser rooftop units are tested with outside air dampers at minimum setting (unit in heating mode).

The results described in Table 2 compare outside air % to various physical parameters of the unit such as damper area and economiser cycle. The listing is organized to show results according to increasing outside air %. Economiser units are grouped separately in Table 2.

The listing shows a large range for outside air percentage. Economiser units vary from about 3% outside air to over 50% outside air. Standard units vary from 0% outside air to 60% outside air. The average leakage rate is 9.9% for standard units and 15.5% for economiser units. Economiser units are providing on average higher outside air percentages.

The outside air percentage is related primarily to the damper area and the damper setting as shown in Table 2. The damper setting is 0% for closed and 100% for full open setting. The actual percentage of outside air is determined by the path of resistance for outside air versus the path of resistance for return air. A damper setting of 0% indicates that controlled air leakage has been set to zero. Outside air percentage in this case is directly related to uncontrolled leakage through or around a closed damper or through cracks in the rooftop shell.

The results in Table 2 show that damper settings of 0% usually result in a lower outside air percentage. Notable exceptions, such as Test 2, involve other mitigating factors. For example, the path for the return air in Test 2 was a lengthy duct. The return air duct increased the resistance in the return air path; the unit responded by drawing more air through and around the outside air dampers.

Physical variables such as shell condition, main filter condition and manufacturer are also compared to outside air % in Table 2. A few rooftop units did have significant cracks in the shell housing. Outside air percentage cannot be directly related to the preceding physical variables with the exception of a large crack in the shell housing.

The supply airflow rate of each rooftop unit is related to floor area in Table 3. The supply air volume rate (RATE) has units of l/sec/$m^2$. RATE varies from a low of less than 3 l/sec/$m^2$ to a high of 13 l/sec/$m^2$--excluding entrance heater rooftop units. The average RATE, excluding entrance heater rooftop units, is 7.0 l/sec/$m^2$. The average RATE for economiser units is not significantly different than the rate for no economiser units.

The outside airflow can now be related to the floor area. Outside airflow per unit of floor area is calculated below:

---

For Economiser Units
Outside Air Supply Rate

= 15.5% outside air x 7.0 average supply air rate l/sec/$m^2$
= 1.0 l/sec/$m^2$

---

For No Economiser Units
Outside Air Supply Rate

= 9.9% outside air x 7.0 average supply air rate l/sec/$m^2$
= 0.7 l/sec/$m^2$

Typical design rates for outside air are 0.5 l/sec/$m^2$. The units without economiser cycles exhibit similar outside air rates at 0.7 l/sec/$m^2$ (average rate). Economiser units are providing twice the design standard at 1.0 l/sec/$m^2$.

The outside air volume is supplied by a rooftop unit during all hours of fan operation. Fan operation is not always coincident with building occupied hours. For example, the fan must operate to supply heating during nights and weekends when ventilation air is not required. In this case, the outside air or ventilation air is not desirable from an energy conservation standpoint. The cost of this undesirable ventilation can be calculated as follows:

1 l/sec outside air heated to 20°C during heating season in Toronto requires 112 kWh/year assuming 24-hour operation.

Assuming a retail store operates 80 hours per week and fuel cost is $.03 per equivalent kWh, the cost of undesirable ventilation air becomes:

Excess Ventilation Energy = 112 kWh x .6 l/sec/$m^2$ x $\frac{(168-80)\text{ hours/non operating}}{168\text{ hours/week}}$ x $.03/kWh

= $1.07/$m^2$ of floor area/year.

A fuel cost of $.03/kWh corresponds to a natural gas cost of $.22/$m^2$ with 70% seasonal heating system efficiency.

This calculation assumes that ventilation air is undesirable during unoccupied hours for the building. The energy penalty of 7.5 kWh/$m^2$/yr. or $1.07/$m^2$/yr. assumes that the fan operation is continuous during operating hours. This energy penalty is discussed in greater detail in Section 5.3.

## 5.2 Combustion Test Analysis

The results of the combustion testing (FEM meter reading) are summarized in Table 4. Combustion efficiency varies from a low of 60% to a high of 77% for gas-fired units. The average combustion efficiency is 69% for gas-fired units. No significant correlation of combustion efficiency to unit age is evident in the test data. Many older units are among the most efficient units.

All combustion test efficiencies measured by the FEM instrument include a 3% adjustment for loss of efficiency due to conduction loss from the rooftop HVAC unit enclosure. No data is currently available on conduction losses for rooftop burner enclosures, consequently the 3% efficiency adjustment is assumed to be adequate. The accuracy of the FEM instrument is stated as 1% for the combustion efficiency reading.

## 5.0 TEST ANALYSIS

The size of the unit as measured by supply air volume in l/sec. is not strongly correlated to combustion efficiency as shown in Table 4. Larger rooftop units may be slightly more efficient; however the trend is not well defined. Many smaller rooftop units are more efficient than larger units as shown in Table 4.

The variation in combustion efficiency can be caused by a number of factors:

1. Improper firing rate due to manifold pressure setting and corrosion deposit buildup on gas burners; firing rate may have been poorly set up during original installation.

2. Primary air adjustment for combustion air mixing; some units provide for a primary air adjustment.

3. Supply air flow across heat exchanger may be inadequate due to blockages or dirty filters; this condition reduces efficiency and may cause premature heat exchanger failure.

4. Heat exchanger may be corroded or damaged causing inter-mixing of supply air and flue gas; this contamination process will reduce firing efficiency. A corroded heat exchanger can be a health hazard if flue gas is allowed to contaminate the supply air to the building.

### 5.3 Operation and Maintenance

The test data for rooftop control and operation is summarized in Table 6. Most units are controlled from a single room mounted thermostat. Typically the thermostat provides for a heating/cooling mode switch and continuous fan/auto fan mode switch. No specific data was

recorded for the position of the continuous fan/auto fan mode switch; however, subsequent review showed four rooftop units of the 51 tested are set to continuous fan operation. Most units are set to fan auto mode.

Operation of the rooftop HVAC unit in the fan auto mode cycles the fan operation with the heating cycle. Consequently no controlled outside air is introduced between heating cycles. The average on time/off time for fan operation is unknown. A conservative estimate of fan on operation is 33% during the heating season. Fan on operation is unlikely to exceed 50% during the heating season.

Thirty-six percent (36%) of all units tested have some form of timeclock or automated control as shown in Table 6. Since a large number of the tests involved large buildings, this percentage is expected to be higher than a sample with more small retail buildings. Less than 10% of smaller buildings have some form of automated control.

No written operating instructions are available concerning rooftop operation. The thermostat settings are not well understood by most building occupants based on site discussions.

Maintenance of filters and dampers in the rooftop units was poor in most buildings. Service contracts are organized on a "breakdown" basis. Small store owners do not invest in preventive maintenance. Larger stores have operations personnel who are responsible for maintenance. In most cases, the large store units are better maintained. Large store units have main filters which are much cleaner.

## 5.0 TEST ANALYSIS

A yearly tune-up for rooftop units may avoid costly breakdowns and improve operating efficiency. A checklist is required for this tune-up. Items on the check list could include:

- combustion test
- adjust firing rate
- primary combustion air setting
- outside air adjustment
- check belts/pulleys
- inspect motor
- inspect heat exchanger
- check cooling cycle operation
- inspect/adjust dampers
- inspect/replace filters.

Thirty percent (30%) of all units tested have night setback for the heating thermostat as shown in Table 6. Less than 10% of the smaller buildings have night setback. Night setback is capable of making substantial energy savings with rooftop units during unoccupied hours. The primary saving from night setback comes from not running the fan while room temperatures fall to setback temperature. Normally, with the fan running, outside air must be heated during unoccupied hours for the building. As noted previously, the outside air heating can amount to $\$1.07/m^2/yr.$ of floor area with continuous fan operation. The saving may be $43¢/m^2/yr.$ for standard rooftop units operated in the FAN AUTO mode. The $43\ ¢/m^2/yr.$ saving assumes that the fan operates 40% of all hours in the setback period.

Microprocessor based thermostats are now available for about $150/unit from a number of manufacturers and suppliers of HVAC equipment. This type of thermostat can be programmed for night setback and temperature set down during weekends. Assuming a store size of 500 $m^2$, a savings of $10¢/m^2/yr.$ will give a three year simple payback. All thermostats should be placed on the FAN AUTO setting to achieve maximum energy savings. The setback temperature of 15°C is acceptable for most buildings.

The application of the economiser cycle for rooftop units may not save energy. Assuming cooling energy for a retail building is 20 kWh/$m^2$/yr., the cooling cost is \$1.00/$m^2$/yr. based on electricity costs of \$.05/kWh.

Typically, an economiser cycle can save up to 50% of cooling energy in a Toronto building. Leakage tests indicate that many economiser rooftop units could waste more heating energy than they save in cooling energy. The additional capital costs of an economiser cycle may have a negative payback if dampers are not properly manufactured or maintained.

## 5.4 Retrofit of Rooftop HVAC Units for Energy Savings

The outside air leakage test can be duplicated by maintenance personnel or a service contractor. The measurement of the supply airflow can be replaced with an assumption regarding the supply air rate per unit of floor area served. Energy savings can be calculated based on the test parameters.

Example

A leakage test performed shows a 20% outside air percentage. The unit tested serves a floor area of 250 $m^2$ .

Assume 7.0 litres/sec/$m^2$ of floor area supply rate.

Assume 1 litre/sec outside air continuous operation = 112 kWh of heating.

Assume 1 kWh heating = \$.03/kWh.

Assume rooftop operates for 33% of hours in heating season.

The supply air rate of the rooftop unit is calculated below:

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Supply air rate = 7.0 x 250 = 1750 litres/sec.

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The outside air rate is calculated as follows:

---

Outside air rate = 20% x 1750 = 350 litres/sec.

---

A reduction in outside air leakage to 10% from 20% will produce estimated savings of:

---

Savings/year = 350 x 1/2 x 112 x 33% x $.03
= $194/year

---

The savings calculated above assumed the rooftop HVAC unit was operated in the FAN AUTO position. Savings will be proportionately greater for FAN CONTINUOUS operation.

Reduction of outside air percentage will involve one of the following actions:

1. Adjust outside air slot opening for no economiser units.

2. Re-seal obvious rooftop shell cracks.

3. Adjust damper seals for economiser units for better fit and/or adjust damper minimum position.

4. Reduce return air path resistance.

## 5.0 TEST ANALYSIS

The potential for reduction of outside air volumes is present in 50% of all units tested. The energy saving potential for all Canada can be estimated as follows:

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Potential Energy Savings

$$\text{All Units} = 160{,}000 \text{ units} \times \frac{50}{100} \times \$200 \text{ savings/yr.}$$

$$= \$16{,}000{,}000/\text{year}$$

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TABLE 1 - SUMMARY OF COMBUSTION EFFICIENCY AND OUTSIDE AIR LEAKAGE

| TEST # | FUEL TYPE | ROOFTOP UNIT AGE YEARS | ROOFTOP TYPE | ECONOMISER | COMBUSTION % EFFICIENCY | OUTSIDE AIR LEAKAGE % |
|---|---|---|---|---|---|---|
| 1 | GAS | 1 | CARRIER | NO | 70.4 | 5.8 |
| 2 | GAS | 1 | CARRIER 48EP008 | YES | 71.3 | 53.1 |
| 3 | ELECTRICITY | 10 | I.T.T. | YES | N/A | 7.6 |
| 4 | ELECTRICITY | 10 | I.T.T. | YES | N/A | 7.6 |
| 5 | GAS | 8 | CARRIER | YES | 73.0 | 2.8 |
| 6 | GAS | 8 | CARRIER | YES | 69.7 | 9.3 |
| 7 | GAS | 8 | CARRIER | YES | 70.6 | 11.7 |
| 8 | GAS | 8 | CARRIER | YES | 64.9 | 8.1 |
| 9 | GAS | 6 | LENNOX | NO | 72.6 | 5.8 |
| 10 | GAS | 1 | KEEPRITE | YES | 76.7 | 3.8 |
| 11 | GAS | 4 | SINGER | NO | 73.7 | 3.4 |
| 12 | GAS | 4 | SINGER | NO | 69.4 | 3.7 |
| 13 | GAS | 3 | REZNOR I.T.T. | YES | 74.8 | 6.8 |
| 14 | GAS | 3 | REZNOR I.T.T. | YES | 74.1 | 9.3 |
| 15 | GAS | 3 | REZNOR I.T.T. | YES | 77.0 | 21.9 |
| 16 | GAS | 1 | YORK | YES | 72.7 | 4.3 |
| 17 | GAS | 1 | YORK | YES | 72.1 | 13.0 |
| 18 | GAS | 4 | CARRIER | YES | 71.4 | 9.3 |
| 19 | GAS | 3 | LENNOX | YES | 72.9 | 16.6 |
| 20 | GAS | 3 | LENNOX | YES | 74.7 | 36.3 |
| 21 | GAS | 16 | MELCO | NO | 68.4 | 0 |
| 22 | GAS | 16 | MELCO | NO | 74.0 | 0 |
| 23 | GAS | 3 | CARRIER | NO | 65.2 | 6.1 |
| 24 | GAS | 3 | CARRIER | NO | 67.1 | 10.4 |
| 25 | GAS | 3 | CARRIER | NO | 75.3 | 6.1 |
| 26 | GAS | 3 | CARRIER | NO | 70.1 | 8.3 |
| 27 | GAS | 5 | SINGER | NO | 60.9 | 10.0 |
| 28 | GAS | 5 | SINGER | NO | 60.3 | 33.3 |
| 29 | GAS | 5 | SINGER | NO | 60.8 | 0 |
| 30 | GAS | 8 | YORK | NO | 76.3 | 13.0 |
| 31 | GAS | 8 | YORK | NO | 67.9 | 4.3 |
| 32 | GAS | 8 | YORK | NO | 70.6 | 60.0 |
| 33 | GAS | 8 | YORK | NO | 72.1 | 10.3 |
| 34 | GAS | 8 | YORK | NO | 70.4 | 0 |
| 35 | GAS | 15 | YORK | NO | 75.1 | 8.5 |
| 36 | GAS | 15 | YORK | NO | 70.8 | 8.3 |
| 37 | GAS | 8 | REZNOR | NO | 68.4 | N/A |
| 38 | GAS | 8 | REZNOR | NO | 65.9 | N/A |
| 39 | GAS | 8 | REZNOR | NO | 67.2 | N/A |
| 40 | GAS | 12 | KEEPRITE | NO | 71.7 | 2.4 |
| 41 | GAS | 12 | KEEPRITE | NO | 71.5 | 34.2 |
| 42 | GAS | 12 | KEEPRITE | NO | 67.8 | 8.3 |
| 43 | GAS | 4 | CARRIER | NO | 70.0 | 3.4 |
| 44 | GAS | 1 | CARRIER | NO | 71.0 | 6.6 |
| 45 | GAS | 8 | CARRIER | NO | 65.6 | 5.4 |
| 46 | GAS | 5 | YORK | NO | 68.8 | 6.2 |
| 47 | GAS | 2 | DELHI | NO | 70.5 | 10.0 |
| 48 | GAS | 2 | DELHI | NO | 71.0 | 10.0 |
| 49 | GAS | 2 | DELHI | NO | 71.2 | 20.0 |
| 50 | GAS | 6 | TRANE | YES | 76.4 | 41.1 |
| 51 | GAS | 12 | YORK | NO | 75.2 | 4.1 |

TABLE 2 - RELATIONSHIP OF OUTSIDE AIR LEAKAGE % TO PHYSICAL CHARACTERISTICS OF ROOFTOP UNIT

| TEST # | FUEL TYPE | UNIT AGE YRS. | ROOFTOP UNIT TYPE | ECONOMISER | SHELL CONDITION | FILTER CONDITION | DAMPER AREA $M^2$ x 10 | DAMPER SETTING % OPEN | OUTSIDE AIR LEAKAGE % |
|---|---|---|---|---|---|---|---|---|---|
| 21 | GAS | 16 | MELCO | NO | GOOD | POOR | .16 | 0 | 0.0 |
| 22 | GAS | 16 | MELCO | NO | FAIR | FAIR | .16 | 0 | 0.0 |
| 29 | GAS | 5 | SINGER | NO | GOOD | POOR | .04 | 15 | 0.0 |
| 34 | GAS | 8 | YORK | NO | GOOD | GOOD | .08 | 5 | N/A |
| 37 | GAS | 8 | REZNOR | NO | FAIR | GOOD | 0 | 0 | N/A |
| 38 | GAS | 8 | REZNOR | NO | FAIR | GOOD | 0 | 0 | N/A |
| 39 | GAS | 8 | REZNOR | NO | FAIR | GOOD | 0 | 0 | 0.0 |
| 40 | GAS | 12 | KEEPRITE | NO | GOOD | FAIR | 0 | 0 | 2.4 |
| 11 | GAS | 4 | SINGER | NO | GOOD | POOR | .03 | 5 | 3.4 |
| 43 | GAS | 4 | CARRIER | NO | GOOD | GOOD | 0 | 0 | 3.4 |
| 12 | GAS | 4 | SINGER | NO | GOOD | POOR | .03 | 0 | 3.7 |
| 51 | GAS | 12 | YORK | NO | GOOD | FAIR | 0 | 0 | 4.1 |
| 31 | GAS | 8 | YORK | NO | GOOD | GOOD | .22 | 5 | 4.3 |
| 45 | GAS | 8 | CARRIER | NO | GOOD | FAIR | 0 | 0 | 5.4 |
| 1 | GAS | 1 | CARRIER | NO | GOOD | POOR | .05 | 80 | 5.8 |
| 9 | GAS | 6 | LENNOR | NO | GOOD | GOOD | .24 | 5 | 5.8 |
| 23 | GAS | 3 | CARRIER | NO | GOOD | FAIR | .04 | 5 | 6.1 |
| 25 | GAS | 3 | CARRIER | NO | GOOD | GOOD | .06 | 10 | 6.1 |
| 46 | GAS | 5 | YORK | NO | FAIR | FAIR | 0 | 0 | 6.2 |
| 44 | GAS | 1 | CARRIER | NO | GOOD | GOOD | 0 | 0 | 6.6 |
| 26 | GAS | 3 | CARRIER | NO | GOOD | GOOD | .05 | 10 | 8.3 |
| 36 | GAS | 15 | YORK | NO | FAIR | POOR | 0 | 0 | 8.3 |
| 42 | GAS | 12 | KEEPRITE | NO | FAIR | FAIR | .17 | 15 | 8.3 |
| 35 | GAS | 15 | YORK | NO | FAIR | POOR | 0 | 0 | 8.5 |
| 27 | GAS | 5 | SINGER | NO | GOOD | POOR | .04 | 20 | 10.0 |
| 47 | GAS | 2 | DELHI | NO | GOOD | FAIR | .07 | 2 | 10.0 |
| 48 | GAS | 2 | DELHI | NO | GOOD | FAIR | .07 | 2 | 10.0 |
| 33 | GAS | 8 | YORK | NO | GOOD | GOOD | .15 | 10 | 10.3 |
| 24 | GAS | 3 | CARRIER | NO | GOOD | GOOD | .02 | 10 | 10.4 |
| 30 | GAS | 8 | YORK | NO | GOOD | GOOD | .07 | 15 | 13.0 |
| 49 | GAS | 2 | DELHI | NO | GOOD | FAIR | .07 | 5 | 20.0 |
| 28 | GAS | 5 | SINGER | NO | FAIR | POOR | .04 | 25 | 33.3 |
| 41 | GAS | 12 | KEEPRITE | NO | GOOD | FAIR | .17 | 15 | 34.2 |
| 32 | GAS | 8 | YORK | NO | GOOD | GOOD | .07 | 15 | 60.0 |
| 5 | GAS | 8 | CARRIER | YES | FAIR | FAIR | .56 | 0 | 2.8 |
| 10 | GAS | 1 | KEEPRITE | YES | GOOD | GOOD | .38 | 0 | 3.8 |
| 16 | GAS | 1 | YORK | YES | GOOD | GOOD | .37 | 0 | 4.3 |
| 13 | GAS | 3 | REZNOR I.T.T. | YES | GOOD | FAIR | .47 | 10 | 6.8 |
| 3 | ELEC. | 10 | I.T.T. | YES | GOOD | GOOD | .68 | 0 | 7.6 |
| 4 | ELEC. | 10 | I.T.T. | YES | GOOD | GOOD | .68 | 0 | 7.6 |
| 8 | GAS | 8 | CARRIER | YES | FAIR | FAIR | .07 | 0 | 8.1 |
| 14 | GAS | 3 | REZNOR I.T.T. | YES | GOOD | FAIR | .47 | 10 | 9.3 |
| 6 | GAS | 8 | CARRIER | YES | FAIR | FAIR | .56 | 0 | 9.3 |
| 18 | GAS | 4 | CARRIER | YES | GOOD | FAIR | .58 | 0 | 9.3 |
| 7 | GAS | 8 | CARRIER | YES | FAIR | FAIR | .06 | 0 | 11.7 |
| 17 | GAS | 1 | YORK | YES | GOOD | FAIR | .39 | 0 | 13.04 |
| 19 | GAS | 3 | LENNOX | YES | GOOD | FAIR | .29 | 10 | 16.67 |
| 15 | GAS | 3 | REZNOR I.T.T. | YES | GOOD | FAIR | .47 | 10 | 21.95 |
| 20 | GAS | 3 | LENNOX | YES | GOOD | FAIR | .29 | 30 | 36.36 |
| 50 | GAS | 6 | TRANE | YES | GOOD | POOR | .70 | 0 | 41.18 |
| 2 | GAS | 1 | CARRIER 48EP008 | YES | GOOD | POOR | .35 | 0 | 53.13 |

TABLE 3 - SUMMARY OF SUPPLY AIR VOLUME RATES PER UNIT OF FLOOR AREA

| TEST # | FUEL TYPE | ROOFTOP UNIT TYPE | UNIT AGE YRS. | ECONOMISER | SUPPLY AIR VOLUME RATE L/SEC/M $^2$ |
|---|---|---|---|---|---|
| 34 | GAS | YORK | 8 | NO | 3.4 |
| 33 | GAS | YORK | 8 | NO | 3.9 |
| 27 | GAS | SINGER | 5 | NO | 4.7 |
| 28 | GAS | SINGER | 5 | NO | 4.9 |
| 1 | GAS | CARRIER | 1 | NO | 5.1 |
| 29 | GAS | SINGER | 5 | NO | 5.1 |
| 32 | GAS | YORK | 8 | NO | 5.8 |
| 36 | GAS | YORK | 15 | NO | 5.9 |
| 35 | GAS | YORK | 15 | NO | 6.0 |
| 9 | GAS | LENNOX | 6 | NO | 6.2 |
| 46 | GAS | YORK | 5 | NO | 6.2 |
| 24 | GAS | CARRIER | 3 | NO | 6.3 |
| 44 | GAS | CARRIER | 1 | NO | 6.3 |
| 26 | GAS | CARRIER | 3 | NO | 6.6 |
| 42 | GAS | KEEPRITE | 12 | NO | 6.8 |
| 45 | GAS | CARRIER | 8 | NO | 7.0 |
| 30 | GAS | YORK | 8 | NO | 7.2 |
| 41 | GAS | KEEPRITE | 12 | NO | 7.2 |
| 23 | GAS | CARRIER | 3 | NO | 7.2 |
| 43 | GAS | CARRIER | 4 | NO | 7.5 |
| 40 | GAS | KEEPRITE | 12 | NO | 7.8 |
| 47 | GAS | DELHI | 2 | NO | 7.9 |
| 51 | GAS | YORK | 12 | NO | 8.2 |
| 48 | GAS | DELHI | 2 | NO | 8.2 |
| 49 | GAS | DELHI | 2 | NO | 8.2 |
| 31 | GAS | YORK | 8 | NO | 8.5 |
| 21 | GAS | MELCO | 16 | NO | 9.9 |
| 22 | GAS | MELCO | 16 | NO | 9.9 |
| 37 | GAS | REZNOR | 8 | NO | 10.2 |
| 25 | GAS | CARRIER | 3 | NO | 10.5 |
| 11 | GAS | SINGER | 4 | NO | 10.6 |
| 12 | GAS | SINGER | 4 | NO | 10.8 |
| 38 | GAS | REZNOR | 8 | NO | 44.6 |
| 39 | GAS | REZNOR | 8 | NO | 44.6 |
| 13 | GAS | REZNOR I.T.T. | 3 | YES | 2.4 |
| 14 | GAS | REZNOR I.T.T. | 3 | YES | 2.4 |
| 15 | GAS | REZNOR I.T.T. | 3 | YES | 2.9 |
| 18 | GAS | CARRIER | 4 | YES | 3.0 |
| 3 | ELEC. | I.T.T. | 10 | YES | 5.9 |
| 4 | ELEC. | I.T.T. | 10 | YES | 5.9 |
| 10 | GAS | KEEPRITE | 1 | YES | 6.1 |
| 50 | GAS | TRANE | 6 | YES | 6.1 |
| 7 | GAS | CARRIER | 8 | YES | 6.8 |
| 8 | GAS | CARRIER | 8 | YES | 7.0 |
| 6 | GAS | CARRIER | 8 | YES | 7.6 |
| 5 | GAS | CARRIER | 8 | YES | 7.8 |
| 19 | GAS | LENNOX | 3 | YES | 8.4 |
| 20 | GAS | LENNOX | 3 | YES | 8.4 |
| 2 | GAS | CARRIER 48EP008 | 1 | YES | 9.3 |
| 16 | GAS | YORK | 1 | YES | 10.9 |
| 17 | GAS | YORK | 1 | YES | 13.6 |

TABLE 4 - RELATIONSHIP OF SUPPLY AIR RATE TO COMBUSTION TEST RESULTS & PHYSICAL PARAMETERS OF ROOFTOP UNITS

| TEST # | FUEL TYPE | ROOFTOP UNIT AGE | ROOFTOP TYPE | ECONOMISER | FLUE GAS OXYGEN % | FLUE GAS DELTA T°C | COMBUSTION EFFICIENCY % | SUPPLY AIR VOLUME L/SEC |
|---|---|---|---|---|---|---|---|---|
| 28 | GAS | 5 | SINGER | NO | 14.9 | 248 | 60.3 | 638 |
| 29 | GAS | 5 | SINGER | NO | 14.5 | 260 | 60.8 | 567 |
| 27 | GAS | 5 | SINGER | NO | 14.4 | 264 | 60.9 | 614 |
| 23 | GAS | 3 | CARRIER | NO | 14.7 | 210 | 65.2 | 3784 |
| 45 | GAS | 8 | CARRIER | NO | 10.7 | 240 | 65.6 | 780 |
| 38 | GAS | 8 | REZNOR | NO | 10.1 | 333 | 65.9 | 1655 |
| 24 | GAS | 3 | CARRIER | NO | 10.7 | 205 | 67.1 | 709 |
| 39 | GAS | 8 | REZNOR | NO | 9.2 | 337 | 67.2 | 1655 |
| 42 | GAS | 12 | KEEPRITE | NO | 13.1 | 230 | 67.8 | 3784 |
| 31 | GAS | 8 | YORK | NO | 10.6 | 392 | 67.9 | 2601 |
| 46 | GAS | 5 | YORK | NO | 10.8 | 295 | 68.0 | 2033 |
| 21 | GAS | 16 | MELCO | NO | 16.2 | 140 | 68.4 | 5912 |
| 37 | GAS | 8 | REZNOR | NO | 11.5 | 263 | 68.4 | 1892 |
| 12 | GAS | 4 | SINGER | NO | 10.8 | 264 | 69.4 | 482 |
| 43 | GAS | 4 | CARRIER | NO | 9.0 | 280 | 70.0 | 4067 |
| 26 | GAS | 3 | CARRIER | NO | 9.8 | 204 | 70.1 | 614 |
| 34 | GAS | 8 | YORK | NO | 10.2 | 263 | 70.4 | 1892 |
| 1 | GAS | 1 | CARRIER | NO | 11.5 | 234 | 70.4 | 1419 |
| 47 | GAS | 2 | DELHI | NO | 8.8 | 292 | 70.5 | 5912 |
| 32 | GAS | 8 | YORK | NO | 9.1 | 285 | 70.6 | 756 |
| 36 | GAS | 15 | YORK | NO | 6.7 | 329 | 70.8 | 1655 |
| 44 | GAS | 1 | CARRIER | NO | 9.1 | 265 | 71.0 | 1892 |
| 48 | GAS | 2 | DELHI | NO | 8.5 | 288 | 71.0 | 6149 |
| 49 | GAS | 2 | DELHI | NO | 11.8 | 218 | 71.2 | 6149 |
| 41 | GAS | 12 | KEEPRITE | NO | 11.2 | 226 | 71.5 | 4020 |
| 40 | GAS | 12 | KEEPRITE | NO | 12.7 | 193 | 71.7 | 946 |
| 33 | GAS | 8 | YORK | NO | 9.1 | 259 | 72.1 | 4730 |
| 9 | GAS | 6 | LENNOX | NO | 10.8 | 220 | 72.6 | 3121 |
| 11 | GAS | 4 | SINGER | NO | 7.8 | 255 | 73.7 | 473 |
| 22 | GAS | 16 | MELCO | NO | 15.1 | 136 | 74.0 | 5912 |
| 35 | GAS | 15 | YORK | NO | 6.8 | 321 | 75.1 | 1892 |
| 51 | GAS | 12 | YORK | NO | 8.4 | 218 | 75.2 | 4871 |
| 25 | GAS | 3 | CARRIER | NO | 10.1 | 179 | 75.3 | 1371 |
| 30 | GAS | 8 | YORK | NO | 7.6 | 210 | 76.3 | 804 |
| 8 | GAS | 8 | CARRIER | YES | 11.4 | 311 | 64.9 | 650 |
| 6 | GAS | 8 | CARRIER | YES | 11.5 | 239 | 69.7 | 4257 |
| 7 | GAS | 8 | CARRIER | YES | 11.5 | 235 | 70.6 | 508 |
| 2 | GAS | 1 | CARRIER 48EP008 | YES | 11.8 | 230 | 71.3 | 1466 |
| 18 | GAS | 4 | CARRIER | YES | 10.9 | 261 | 71.4 | 4729 |
| 17 | GAS | 1 | YORK | YES | 8.6 | 284 | 72.1 | 1513 |
| 16 | GAS | 1 | YORK | YES | 7.0 | 285 | 72.7 | 709 |
| 19 | GAS | 3 | LENNOX | YES | 12.2 | 192 | 72.9 | 4729 |
| 5 | GAS | 8 | CARRIER | YES | 11.8 | 195 | 73.0 | 4351 |
| 14 | GAS | 3 | REZNOR I.T.T. | YES | 5.7 | 277 | 74.1 | 4730 |
| 20 | GAS | 3 | LENNOX | YES | 9.6 | 207 | 74.7 | 4729 |
| 13 | GAS | 3 | REZNOR I.T.T. | YES | 7.5 | 277 | 74.8 | 4730 |
| 50 | GAS | 6 | TRANE | YES | 12.2 | 144 | 76.4 | 5676 |
| 10 | GAS | 1 | KEEPRITE | YES | 9.3 | 179 | 76.7 | 1419 |
| 15 | GAS | 3 | REZNOR I.T.T. | YES | 5.4 | 276 | 77.0 | 4730 |
| 3 | ELEC. | 10 | I.T.T. | YES | N/A | N/A | N/A | 4493 |
| 4 | ELEC. | 10 | I.T.T. | YES | N/A | N/A | N/A | 4493 |

TABLE 5 - RELATIONSHIP OF COMBUSTION EFFICIENCY TO OTHER ROOFTOP UNIT PARAMETERS

| TEST # | FUEL TYPE | ROOFTOP UNIT AGE YRS. | ECONOMISER | SUPPLY AIR VOLUME L/SEC | FLUE GAS DELTA T°C | COMBUSTION EFFICIENCY % |
|---|---|---|---|---|---|---|
| 28 | GAS | 5 | NO | 638 | 248 | 60.3 |
| 29 | GAS | 5 | NO | 567 | 260 | 60.8 |
| 27 | GAS | 5 | NO | 614 | 264 | 60.9 |
| 8 | GAS | 8 | YES | 650 | 311 | 64.9 |
| 23 | GAS | 3 | NO | 3784 | 210 | 65.2 |
| 45 | GAS | 8 | NO | 780 | 240 | 65.6 |
| 38 | GAS | 8 | NO | 1655 | 333 | 65.9 |
| 24 | GAS | 3 | NO | 709 | 205 | 67.1 |
| 39 | GAS | 8 | NO | 1655 | 337 | 67.2 |
| 42 | GAS | 12 | NO | 3784 | 230 | 67.8 |
| 31 | GAS | 8 | NO | 2601 | 292 | 67.9 |
| 46 | GAS | 5 | NO | 2033 | 295 | 68.0 |
| 21 | GAS | 16 | NO | 5912 | 140 | 68.4 |
| 37 | GAS | 8 | NO | 1892 | 263 | 68.4 |
| 12 | GAS | 4 | NO | 482 | 264 | 69.4 |
| 6 | GAS | 8 | YES | 4257 | 239 | 69.7 |
| 43 | GAS | 4 | NO | 4067 | 280 | 70.0 |
| 26 | GAS | 3 | NO | 614 | 204 | 70.1 |
| 34 | GAS | 8 | NO | 1892 | 263 | 70.4 |
| 1 | GAS | 1 | NO | 1419 | 234 | 70.4 |
| 47 | GAS | 2 | NO | 5912 | 292 | 70.5 |
| 7 | GAS | 8 | YES | 508 | 235 | 70.6 |
| 32 | GAS | 8 | NO | 756 | 285 | 70.6 |
| 36 | GAS | 15 | NO | 1655 | 329 | 70.8 |
| 44 | GAS | 1 | NO | 1892 | 265 | 71.0 |
| 48 | GAS | 2 | NO | 6149 | 288 | 71.0 |
| 49 | GAS | 2 | NO | 6149 | 218 | 71.2 |
| 2 | GAS | 1 | YES | 1466 | 230 | 71.3 |
| 18 | GAS | 4 | YES | 4729 | 261 | 71.4 |
| 41 | GAS | 12 | NO | 4020 | 226 | 71.5 |
| 40 | GAS | 12 | NO | 946 | 193 | 71.5 |
| 17 | GAS | 1 | YES | 1513 | 284 | 72.1 |
| 33 | GAS | 8 | NO | 4730 | 259 | 72.1 |
| 9 | GAS | 6 | NO | 3121 | 220 | 72.6 |
| 16 | GAS | 1 | YES | 709 | 285 | 72.7 |
| 19 | GAS | 3 | YES | 4729 | 192 | 72.9 |
| 5 | GAS | 8 | YES | 4351 | 195 | 73.0 |
| 11 | GAS | 4 | NO | 473 | 255 | 73.7 |
| 22 | GAS | 16 | NO | 5912 | 136 | 74.0 |
| 14 | GAS | 3 | YES | 4730 | 277 | 74.1 |
| 20 | GAS | 3 | YES | 4729 | 207 | 74.7 |
| 13 | GAS | 3 | YES | 4730 | 277 | 74.8 |
| 35 | GAS | 15 | NO | 1892 | 321 | 75.1 |
| 51 | GAS | 12 | NO | 4871 | 218 | 75.2 |
| 25 | GAS | 3 | NO | 1371 | 179 | 75.3 |
| 30 | GAS | 8 | NO | 804 | 210 | 76.3 |
| 50 | GAS | 6 | YES | 5676 | 144 | 76.4 |
| 10 | GAS | 1 | YES | 1419 | 179 | 76.7 |
| 15 | GAS | 3 | YES | 4730 | 276 | 77.0 |
| 3 | ELECTRIC | 10 | YES | 4493 | N/A | N/A |
| 4 | ELECTRIC | 10 | YES | 4493 | N/A | N/A |

## TABLE 6 - SUMMARY OF CONTROL SETTINGS FOR ROOFTOP UNITS

| TEST # | R/TOP UNIT AGE | ROOFTOP TYPE | ECONOMISER | TSTAT SETTING | COOLING | AUTO CONTROL | NIGHT SETBK | TIMECLOCK CONTROL | UNITS/ CONTROL POINT | SUPPLY AIR VOLUME L/SEC |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | CARRIER | NO | 72 | 74 | NO | NO | NO | 1 | 1419 |
| 9 | 6 | LENNOX | NO | 70 | 72 | NO | NO | NO | 1 | 3121 |
| 11 | 4 | SINGER | NO | 70 | 74 | NO | NO | NO | 1 | 473 |
| 12 | 4 | SINGER | NO | 70 | 74 | NO | NO | NO | 1 | 482 |
| 21 | 16 | MELCO | NO | 72 | 75 | NO | NO | NO | 1 | 5912 |
| 22 | 16 | MELCO | NO | 72 | 75 | NO | NO | NO | 1 | 5912 |
| 23 | 3 | CARRIER | NO | 68 | 72 | NO | NO | NO | 1 | 3784 |
| 24 | 3 | CARRIER | NO | 70 | 75 | NO | NO | NO | 1 | 709 |
| 25 | 3 | CARRIER | NO | 70 | 74 | NO | NO | NO | 1 | 1371 |
| 26 | 3 | CARRIER | NO | 70 | 72 | NO | NO | NO | 1 | 614 |
| 27 | 5 | SINGER | NO | 60 | 60 | NO | NO | NO | 1 | 614 |
| 28 | 5 | SINGER | NO | 68 | 68 | NO | NO | NO | 1 | 638 |
| 29 | 5 | SINGER | NO | 72 | 75 | NO | NO | NO | 1 | 567 |
| 30 | 8 | YORK | NO | 68 | 72 | YES | YES | NO | 1 | 804 |
| 31 | 8 | YORK | NO | 68 | 72 | YES | YES | NO | 1 | 2601 |
| 32 | 8 | YORK | NO | 70 | 72 | YES | YES | NO | 1 | 756 |
| 33 | 8 | YORK | NO | 68 | 72 | YES | YES | NO | 1 | 4730 |
| 34 | 8 | YORK | NO | 70 | 74 | YES | YES | NO | 1 | 1892 |
| 35 | 15 | YORK | NO | 72 | 75 | NO | NO | NO | 1 | 1892 |
| 36 | 15 | YORK | NO | 68 | 73 | NO | NO | NO | 1 | 1655 |
| 37 | 8 | REZNOR | NO | 38 | NONE | YES | YES | NO | 1 | 1892 |
| 38 | 8 | REZNOR | NO | 38 | NONE | YES | YES | NO | 1 | 1655 |
| 39 | 8 | REZNOR | NO | 38 | NONE | YES | YES | NO | 1 | 1655 |
| 40 | 12 | KEEPRITE | NO | 68 | 74 | NO | NO | NO | 1 | 946 |
| 41 | 12 | KEEPRITE | NO | 68 | 74 | NO | NO | NO | 1 | 4020 |
| 42 | 12 | KEEPRITE | NO | 68 | 74 | NO | NO | NO | 1 | 3784 |
| 43 | 4 | CARRIER | NO | 68 | 72 | NO | NO | NO | 1 | 4067 |
| 44 | 1 | CARRIER | NO | 68 | 72 | NO | NO | NO | 1 | 1892 |
| 45 | 8 | CARRIER | NO | 65 | 70 | NO | NO | NO | 1 | 780 |
| 46 | 5 | YORK | NO | 70 | 74 | NO | NO | NO | 1 | 2033 |
| 47 | 2 | DELHI | NO | 68 | 78 | NO | NO | NO | 2 | 5912 |
| 48 | 2 | DELHI | NO | 68 | 78 | NO | NO | NO | 2 | 6149 |
| 49 | 2 | DELHI | NO | 68 | 78 | NO | NO | NO | 1 | 6149 |
| 51 | 12 | YORK | NO | 68 | 72 | NO | NO | NO | 1 | 4871 |
| 2 | 1 | CARRIER -48EP008 | YES | 72 | 71 | NO | NO | NO | 1 | 1466 |
| 3 | 10 | I.T.T. | YES | 72 | 75 | YES | YES | NO | 1 | 4493 |
| 4 | 10 | I.T.T. | YES | 72 | 75 | YES | YES | NO | 1 | 4493 |
| 5 | 8 | CARRIER | YES | 68 | 74 | YES | YES | NO | 1 | 4351 |
| 6 | 8 | CARRIER | YES | 68 | 74 | YES | YES | NO | 1 | 4257 |
| 7 | 8 | CARRIER | YES | 68 | 75 | NO | NO | NO | 1 | 508 |
| 8 | 8 | CARRIER | YES | 65 | 70 | NO | NO | NO | 1 | 650 |
| 10 | 1 | KEEPRITE | YES | 68 | 70 | NO | NO | NO | 1 | 1419 |
| 13 | 3 | REZNOR | YES | 68 | NONE | NO | NO | NO | 1 | 4730 |
| 14 | 3 | REZNOR ITT | YES | 68 | NONE | NO | YES | YES | 1 | 4730 |
| 15 | 3 | REZNOR ITT | YES | 68 | NONE | NO | YES | YES | 1 | 4730 |
| 16 | 1 | YORK | YES | 72 | 74 | NO | NO | NO | 1 | 709 |
| 17 | 1 | YORK | YES | 72 | 74 | NO | NO | NO | 1 | 1513 |
| 18 | 4 | CARRIER | YES | 72 | 74 | YES | NO | YES | 1 | 4729 |
| 19 | 3 | LENNOX | YES | 72 | 75 | NO | NO | YES | 1 | 4729 |
| 20 | 3 | LENNOX | YES | 72 | 75 | NO | NO | YES | 1 | 4729 |
| 50 | 6 | TRANE | YES | 68 | 72 | NO | NO | NO | 1 | 5676 |

## 6.0 CONCLUSIONS

The following conclusions are drawn from this study:

1. Operation and maintenance procedures for rooftop units are not well understood by most building occupants. Records are not usually kept for maintenance of rooftop units.

2. Rooftop units are poorly maintained in most buildings. Permanent on-site maintenance personnel provide better maintenance for rooftop units in large retail malls. Smaller retail stores adopt a breakdown maintenance strategy: fix it when it breaks.

3. Economiser rooftop units on average have more outside air leakage than units with no economiser cycle.

4. Outside air leakage can be minimized with lower fan hours of operation for each rooftop unit.

5. Gas-fired combustion efficiency ranged from 60% to 77% for the rooftop units tested. In most cases, combustion efficiency can be improved with minor adjustments to the unit.

# 7.0 RECOMMENDATIONS

## 7.1 System Operation

The operation and maintenance of rooftop equipment is not well understood by the building occupants. No information is available regarding thermostat control settings, thermostat functions, operating strategy or previous maintenance history.

A simple instruction guide can be developed to suit the vast majority of commercial applications. The guide would provide the following data:

- explanation of thermostat control settings
- heating season control strategy
- cooling season control strategy
- maintenance schedule for each rooftop unit
- blank pages for special procedures such as computer control night setback, etc.

The guide can be designed for wall attachment above the thermostat. Payback for this recommendation is difficult to predict; however, the end result will be effective technology transfer.

Service contractors could be used to distribute this guide. From the contractors standpoint, the presentation of the guide will develop good public relations with his customer.

Large retail companies could distribute the guide directly through their store network.

## 7.2 Maintenance Procedures

Better maintenance procedures are required for rooftop equipment. A rooftop HVAC tune-up should encompass more than a perfuctory inspection and change of air filters. Combustion efficiency should be checked on a regular basis and adjustments made as required. A record of maintenance procedures should be kept by the building owner/occupant. A tune up checklist for rooftop equipment should be published in conjunction with major utility companies. Service contractors can model a tune up service on this checklist.

Payback periods for a complete tune up service are expected to be less than 3 years. Assuming a combustion efficiency tune up costs $200, an efficiency increase of 6% will retire the investment in 3 years based on a heating bill of $1200/year for one rooftop unit.

Payback periods are dependent on the frequency period for the tune up procedure. In most cases, the combustion efficiency adjustments are not requuired on an annual basis. The combustion efficiency cannot be divorced from other operating parameters of the rooftop HVAC unit.

## 7.3 Night Setback Thermostat

Replacement of the current thermostat with a programmable microprocessor-based thermostat is recommended where heating bills exceed $\$4.50/m^2$ of building area. Savings of 10% for heating fuel are estimated for a night setback of 15°C and normal 6 day/week daily operation. Potential savings will vary with the condition of the rooftop unit and the operating strategy.

## 7.4 Leakage Tests

Rooftop units can be tested to determine the outside air leakage rate. The test used in this study can be duplicated by a service contractor.

A simplified version of the leakage test can exclude supply air rate measurement. The temperature test readings can determine the percentage of outside air in the supply air. An outside air percentage of less than 10% would indicate acceptable leakage. Leakage rates above 10% require remedial action.

The leakage test can be briefly described in the operation guide noted in the first recommendation. Technology transfer to service contractors can be accomplished through distribution of the guide and workshop sessions sponsored by federal/provincial governments.

The retrofit of a problem rooftop HVAC unit is likely to save about $200/year. The savings are expected to be larger for larger rooftop HVAC units. Economiser units with large damper areas will also generate larger yearly savings.

# INGRES DESCRIPTION

## MANAGEMENT SUMMARY

**INGRES** is a full function relational database management system. As such, it embodies all of the fundamental ideas first proposed by Dr. E.F. Codd of IBM. These ideas include the following:

**A Simple Data Model . . .**

Only relations (tables) are available to a user for storage. All data are stored in a uniform way. No semantic information can be placed in sets, links, associations, parent-child relationships or other network constructs. The advantage of using a simple data structure is that databases are easier to understand, maintain and control.

**That Is Dynamic . . .**

**INGRES** provides simple commands for a user to create and destroy relations dynamically. It is not necessary for a "guru" to specify a schema in advance; applications can grow and evolve naturally. Moreover, the storage structure of a relation can be altered easily and quickly. **INGRES** currently supports relations which are stored as hash tables on up to five fields (key), stored indexed sequential on a key, or stored as a heap with no structure. Any of these possibilities can optionally allow compression of records to reduce use of disk space. In addition, an arbitrary number of secondary indices can be defined for a relation, thereby providing fast alternate access paths.

**With An Integrated Data Dictionary . . .**

All data about the schema, including storage secondary indices, integrity control and protection information, are stored in a data dictionary that is itself a database. All facilities of **INGRES** can be used to access this dictionary. The dictionary is automatically kept correct during alteration of the schema.

**And A High-Level Data Manipulation Language (DML) . . .**

**INGRES** provides a DML called *QUEL (QUE*ry *L*anguage) in which users say what they want done rather than how to do it. With *QUEL*, most transactions can be performed with a single command. For example, data from several relations can be joined together and multiple records can be updated in a single statement. Complete arithmetic capabilities, partial matching to values in the database and aggregation operators (count, max, min, sum, avg) are provided. A "macro" facility allows commonly used command patterns to be stored and executed automatically. All details of processing *QUEL* are handled automatically by **INGRES** and need not be of concern to the user. Efficient processing strategies are selected by **INGRES** using complete information on the available storage structures and indices. Moreover, if the storage structure changes, **INGRES** automatically reevaluates its choice.

**With A Complete Set Of Required Services . . .**

Should the operating system or the hardware fail during the processing of a transaction, **INGRES** will either automatically discontinue or complete the transaction. In addition, concurrent updates by multiple users are supported by automatic locking of the database as necessary. **INGRES** can

either be run interactively from a terminal or used from a host language program. A terminal monitor enables users to edit, enter, print and execute **INGRES** *(QUEL)* commands interactively. Also, a preprocessor called ***EQUEL*** *(**E**mbedded **QUEL**)* allows **INGRES** to be used from programs written in FORTRAN, PASCAL, and "C". COBOL, BASIC, and PL/1 interfaces to **INGRES** will be available soon. **INGRES** provides a facility whereby a user can define alternate VIEWS of the database using the full power of ***QUEL***. This facility is especially useful for supporting obsolete versions of a user database. ***QUEL*** commands on VIEWS are automatically mapped by **INGRES** into appropriate commands on relations which actually exist. Sophisticated integrity constraints and access controls can also be specified by a user. These are automatically enforced by **INGRES** to guarantee data integrity.

**And INGRES Is Supported . . .**

Originally developed as a research prototype at the University of California, Berkeley, **INGRES** has been available since 1976 and is in use at more than 125 UNIX sites. An enhanced version is now available, fully supported, from Relational Technology, Inc. for **VAX** computers using the **VMS** operating system. Relational Technology, Inc. will further enhance **INGRES** with user-oriented features including a report generator, a forms processing interface, a natural language facility, and a graphics package. □

# TECHNICAL DESCRIPTION

**SUPPLIER:** Relational Technology, Inc.
2855 Telegraph Avenue, Suite 515
Berkeley, California 94705 (415) 845-1700

**BASIC FUNCTIONS:**

**INGRES** is a full function relational database management system available on DEC® VAX-11 ™ computers using the **VMS** operating system. **INGRES** consists of:

- Commands to define logical and physical databases
- ***QUEL (QUE**ry **L**anguage)* for interactive data manipulation
- ***EQUEL,*** a precompiler for query language statements embedded in the "C" programming language
- A terminal monitor supporting interactive use
- Facilities for defining VIEWS, specifying PROTECTION predicates and asserting INTEGRITY constraints, and
- Utilities for loading and unloading data and for crash recovery.

**OPERATIONS:**

An **INGRES** database consists of relations (tables), each of which has less than 50 fields and a record width of up to 2040 bytes. Field data types can be 1, 2, or 4-byte integer, 4 or 8-byte floating point, or a fixed length character string up to 255 bytes.

Creating a Database:

An **INGRES** database may be created using the commands:

- **CREATDB** names the database and sets up a skeletal directory
- **CREATE** defines each relation in the database
- **COPY** fills each relation with values from a disk file
- **MODIFY** organizes storage structures of relations.

A relation is defined by giving its name and the (name, type, length) for each of its columns. Once a relation is defined, its value can be bulk-loaded from a **VMS** file using the **COPY** command. Alternatively, values may be loaded using the ***QUEL*** insertion facility.

To structure a relation in storage, the **MODIFY** command is used with one of the following options:

- **HEAP** – unstructured and unsorted
- **HEAPSORT** – sorted
- **ISAM** – indexed sequential
- **HASH** – random hash-addressed

For each of these structures, the **COMPRESSION** option may be applied to remove all repeated characters - thus effectively suppressing blanks, nulls and numeric zero values.

An arbitrary number of secondary indices may be specified. These indices are automatically maintained on updates and utilized in query processing. They are stored as separate relations, can have up to five fields as a key, and contain a pointer to a record with the given key values. **INGRES** stores secondary

indices as relations so that an interested user can, in fact, run retrievals on them.

In all cases, actual record storage, space management and buffering are completely managed by **INGRES**.

Different users of the same data can have different logical databases. These are called VIEWS. Any relation that could be retrieved using the query language is acceptable as a VIEW. All retrievals and most updates on VIEWS are automatically mapped into appropriate operations on underlying real relations. Updates which are ambiguous are refused at run time. Using VIEWS, programs with obsolete versions of the database can continue to run. VIEW definitions are stored in the data dictionary and may be added and removed at any time.

Using an **INGRES** Database:

A user interacts with a database using the data sublanguage ***QUEL*** (***QUE***ry ***L***anguage). ***QUEL*** is non-procedural in that a user specifies a set of records to be retrieved or updated, but does not specify an algorithm to obtain them. ***QUEL*** supports four data manipulation operators:

- **RETRIEVE** finds data based on specified arguments
- **APPEND** adds records to a file
- **REPLACE** replaces (modifies) field(s) in a record
- **DELETE** deletes records.

Further, ***QUEL*** supports complex queries in full generality:

- Commands can span multiple relations and the logical associations between relations can be arbitrarily complex
- Arbitrary arithmetic and parentheses are supported
- The Boolean conjunctions AND, OR, and NOT are supported in full generality
- All comparison operators are available, i.e.,

| | | | |
|---|---|---|---|
| < | Less than | < = | Less than or equal to |
| > | Greater than | > = | Greater than or equal to |
| = | Equal to | = ! | Not equal to |

- Powerful aggregation and grouping operators may be included as part of a query. Aggregation operators include:

| | | | | |
|---|---|---|---|---|
| count | avg | min | sum | any |
| countu | avgu | max | sumu | |

- A macro facility is available to execute commonly used expressions.

Each ***QUEL*** command is parsed at run time and a processing strategy is selected using sophisticated optimization heuristics.

***QUEL*** is available interactively through a terminal monitor or from a host language. The terminal monitor allows a user to enter, print, edit and execute commands in a command buffer. Editing is done using ***SOS*** or a user-specified text editor. A user program may be written in a syntactically acceptable combination of ***QUEL*** and a host language. From the host language, a user can conveniently:

- Iterate over a set of returned records
- Substitute program variables into commands at run time, and
- Refer to database objects as any desired data type.

Host language support is currently available for FORTRAN, PASCAL, and "C".

Controlling an **INGRES** Database:

Data dependent field level security is also provided. The owner of a relation can authorize others to access subsets of his data using the **PERMIT** command. Access rights can be restricted by:

- User-name
- Terminal identifier
- Time of day
- Day of the week, and
- Type of ***QUEL*** command.

Each access right is directed to a particular collection of columns for a subset of the records of a relation. Access rights can be modified at any time and are stored in the data dictionary.

Integrity constraints are also supported by **INGRES**. Any ***QUEL*** qualification whose validity can be determined by examining individual records may be defined as a constraint. **INGRES** will automatically refuse updates which would violate such constraints. Integrity constraints can be added or deleted at any time and are stored in the data dictionary. Integrity control and protection are supported by mapping any user command at run time into a new command with added qualification to perform appropriate checking.

Transaction management and recovery control is supported by **INGRES**. Each ***QUEL*** command is automatically run to completion or backed out if a failure occurs. A so-called "intentions list" is created for each update and changes are installed into the database as the last step. A two-phase commitment protocol is used to guarantee that either all or none of the changes are installed. To recover from a crash where data is lost from the disk, a user must restore a previous checkpoint.

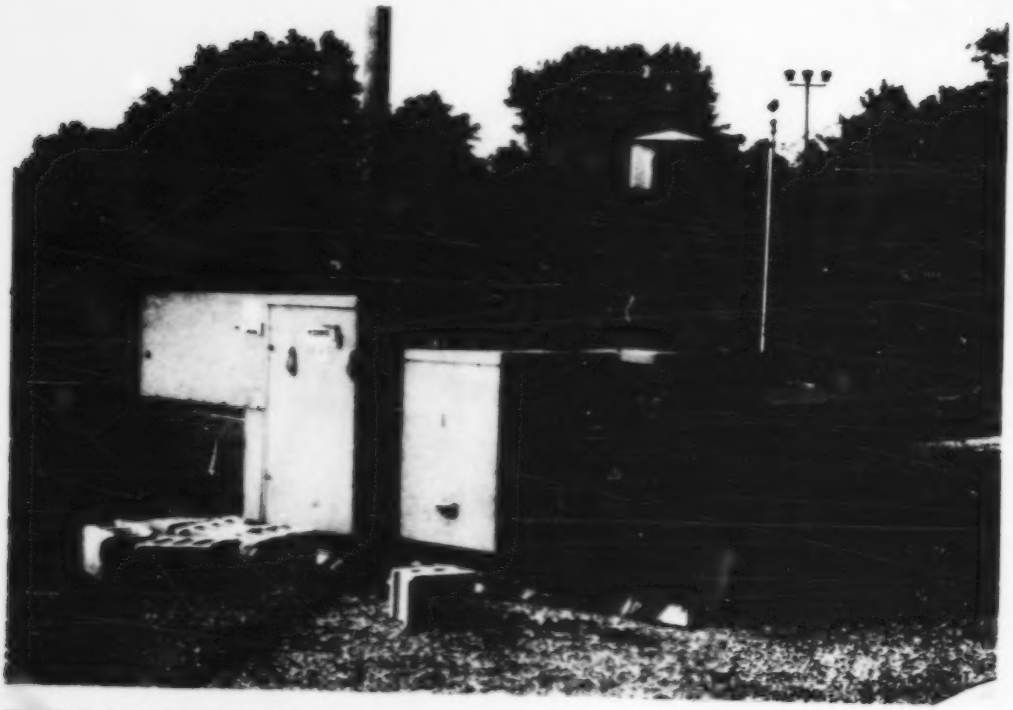
Concurrency control serializes conflicting transactions by means of locks. During command processing, appropriate locks are automatically set and held until the end of a transaction. Locking is performed on either relations or pages, and deadlock is avoided by requesting all resources in advance. The lock table is stored in a separate data segment shared by all concurrently running users.

**FUTURE ENHANCEMENTS:**

Relational Technology has announced the specifications for a report generator, a natural language interface, and a form-based data entry and processing facility. In addition, COBOL, BASIC, and PL/1 interfaces to **INGRES** will be available soon.

**HARDWARE/SOFTWARE REQUIREMENTS:**

**INGRES** is currently available on DEC® VAX-11™ computers using the **VMS** operating system. **INGRES** will run on any **VAX** configuration. □

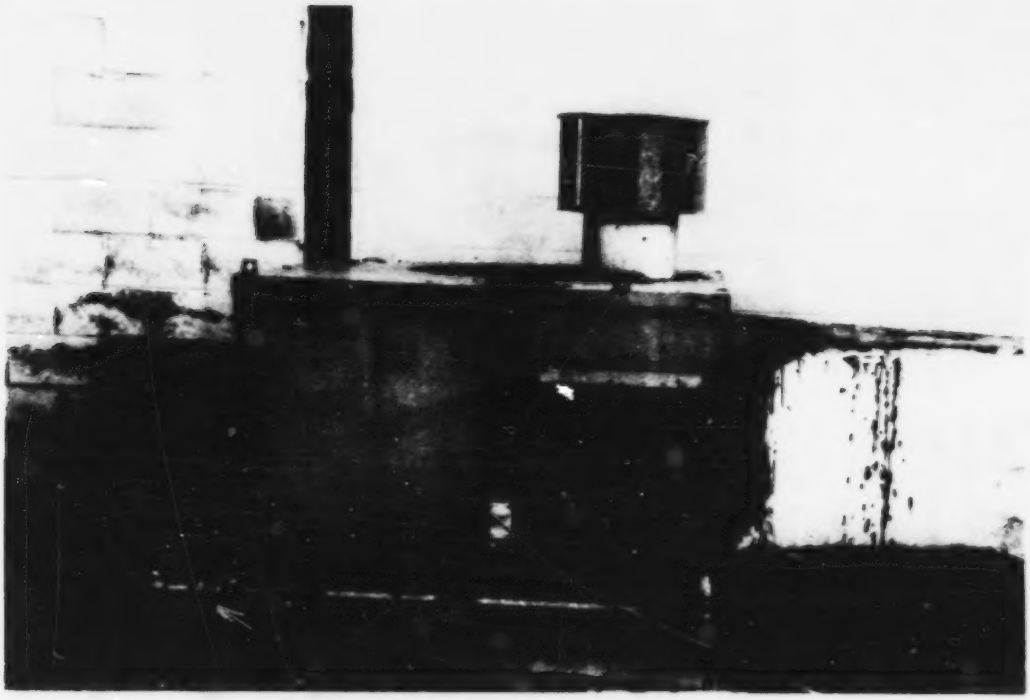


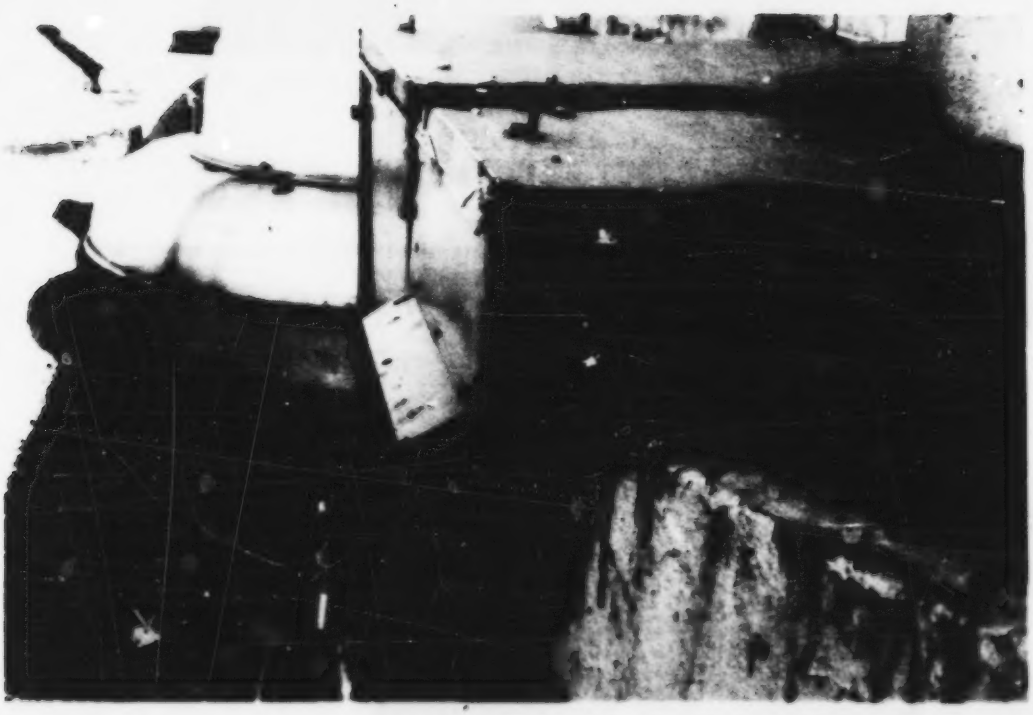
TYPICAL ROOFTOP H.V.A.C. UNIT

ROOFTOP H.V.A.C. UNIT SHOWING ADJUSTABLE OUTSIDE AIR SLOT.

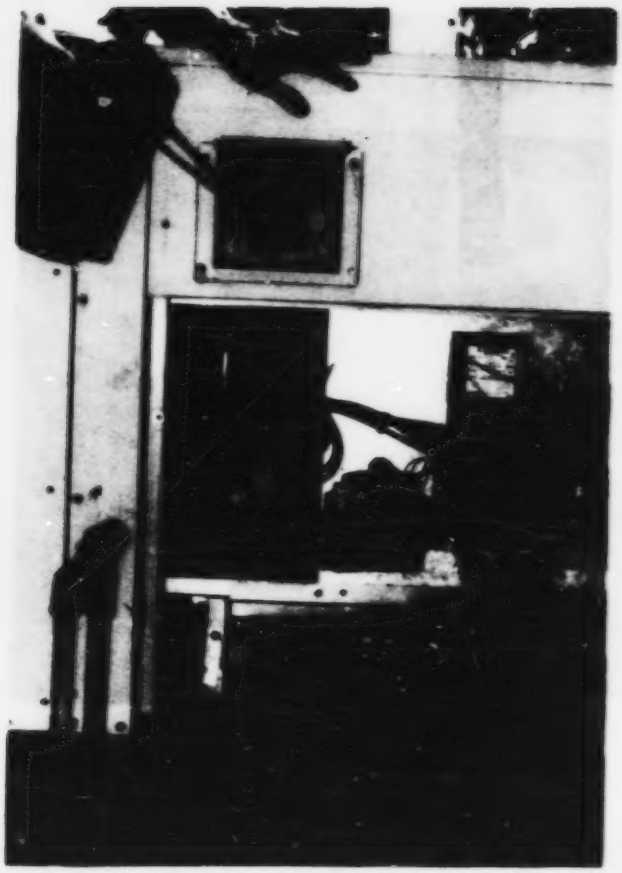
FAN / BELT / MOTOR COMBINATION INSIDE ROOFTOP H.V.A.C. UNIT.

TYPICAL WALL MOUNTED THERMOSTAT FOR ROOFTOP H.V.A.C. CONTROL

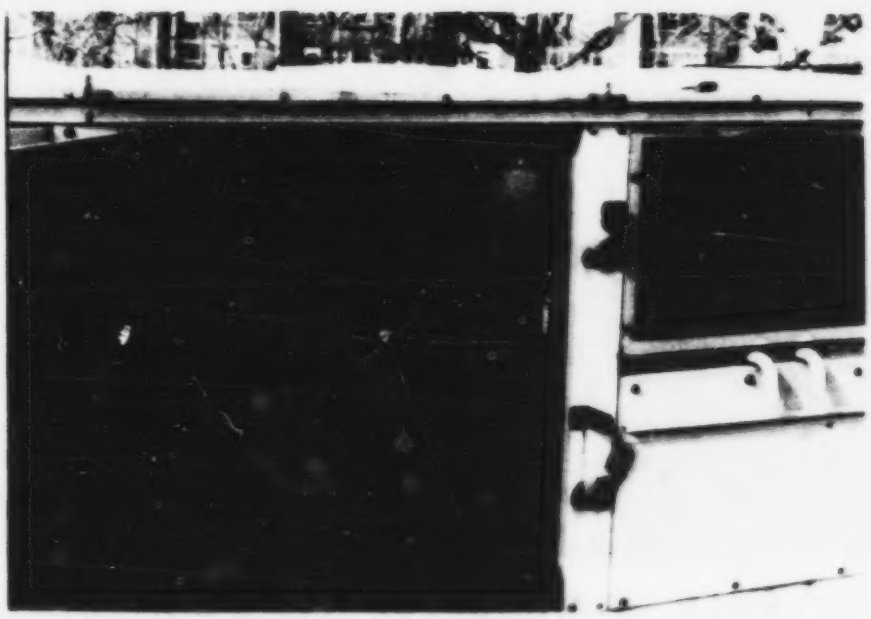




AN EXAMPLE OF A ROOFTOP H.V.A.C. UNIT WITH SOME RETROFIT SEALING TO REDUCE OUTSIDE AIR LEAKAGE.



COMBUSTION EFFICIENCY TEST SHOWING SAMPLING PROBE LOCATION



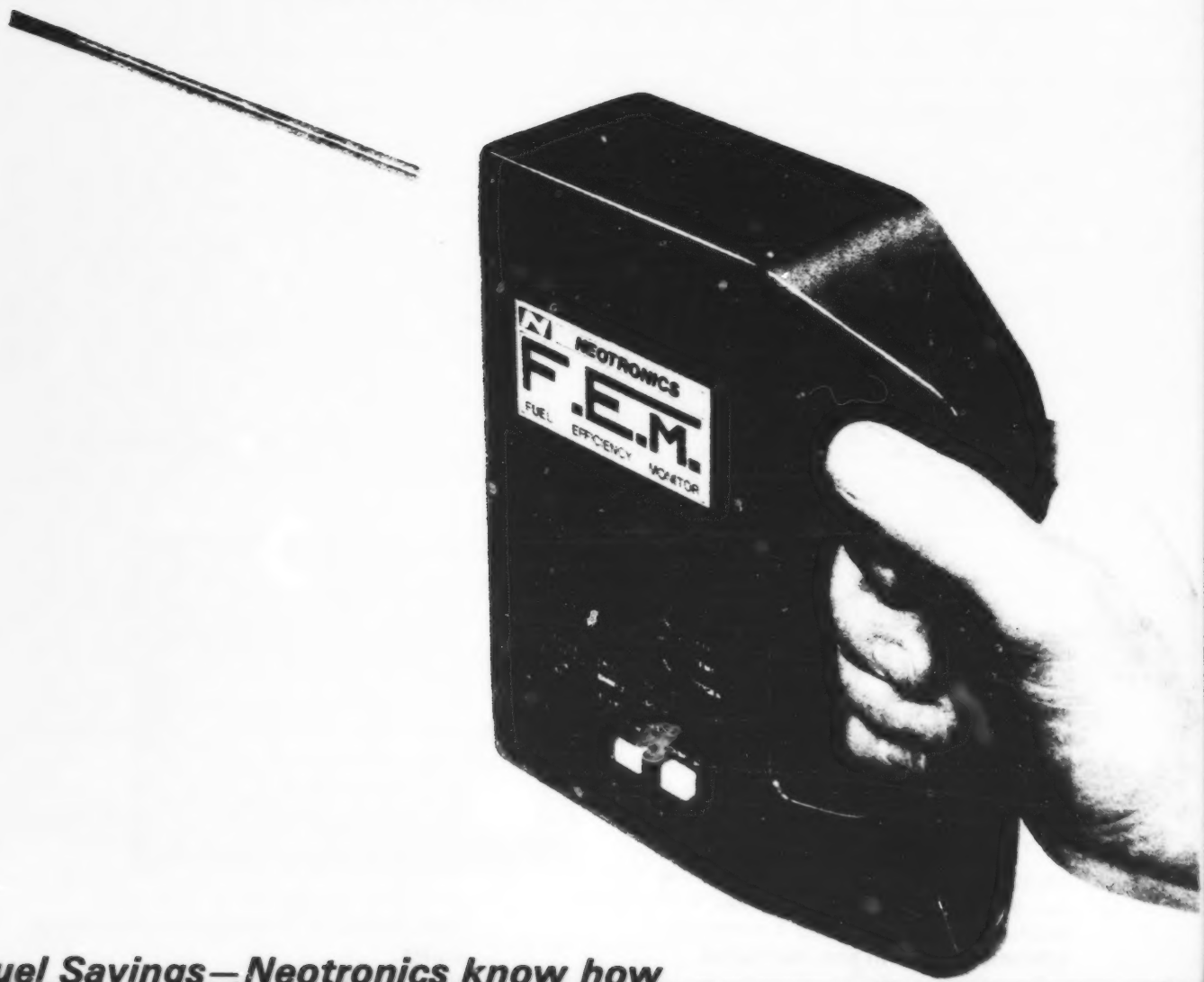
AIR FILTER ASSEMBLY INSIDE ONE ROOFTOP H.V.A.C. UNIT.

**Neotronics Energy Conservation Division**

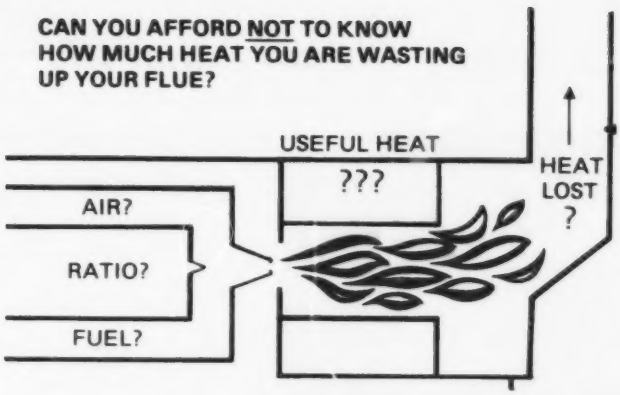


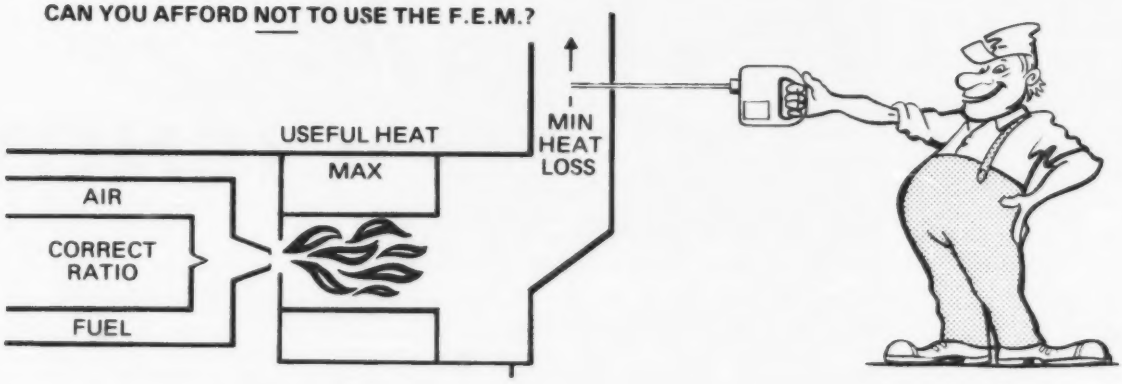
APPENDIX 3 - FEM INFORMATION

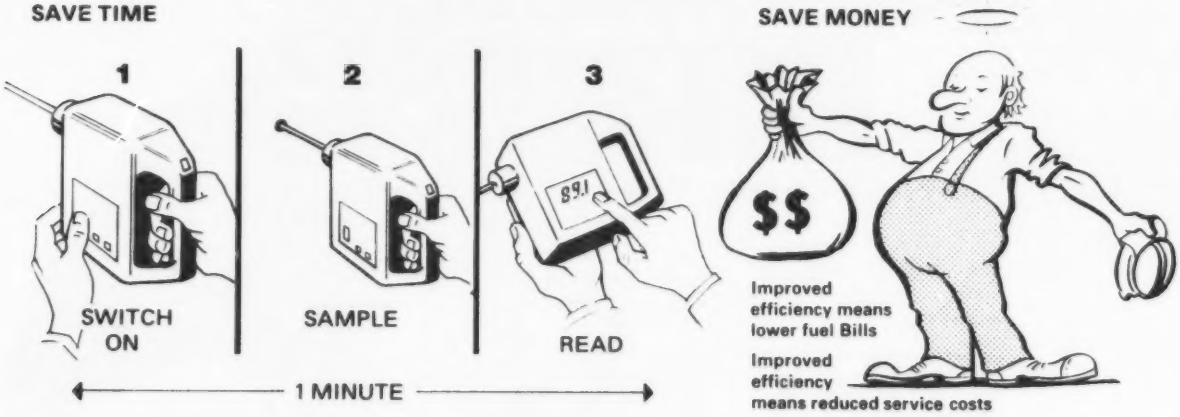
# F.E.M.
# FUEL EFFICIENCY MONITOR




***Fuel Savings—Neotronics know how***






can reduce fuel costs by checking their installations more often and by keeping the fuel/air ratio correctly adjusted to maintain peak efficiency.

For example, with an annual fuel bill of a 10% efficiency improvement will recover the cost of the F.E.M. in far less than one year. In addition, time between services may be optimised if combustion efficiency is known and maintained.

save valuable time by checking and setting up combustion efficiency with the F.E.M. The value of the maintenance service can easily be demonstrated by showing the improvement in combustion efficiency and calculated fuel savings.

can easily ensure effective boiler maintenance as combustion efficiency can be checked quickly and frequently. The information obtained is invaluable for monitoring long term performance of installations and in energy audits.

It needs the latest sophisticated microprocessor technology to perform within one minute automatically, that which used to take highly skilled labor very much longer.

We have kept all the complexity inside the F.E.M., however. Using the instrument is simplicity itself and it is designed to withstand the tough working environment of the boiler house and industry, working reliably for years with the minimum of attention.

The oxygen sensor is an electrochemical cell, many thousands of which have proven their worth over several years in environments even more adverse than those of boiler houses. Extremely good temperature and pressure stability combined with reliability and low replacement price, have made the CTL sensor the obvious choice. Expected life is 8 months and the sensor is guaranteed for 6 months.

Temperature is measured by a Ni-Cr/Ni-Al thermocouple in a specially designed probe to provide fast, accurate response combined with ruggedness and reliability.

When the F.E.M. is switched on, the oxygen sensor is automatically calibrated to normal atmospheric oxygen (20.9%) and the temperature system is calibrated to ambient temperature. This ensures that the true oxygen content and the differential temperature of the flue gas are recorded. Any errors due to variation in ambient temperature in the boiler house are, therefore, automatically eliminated.

The F.E.M. is suitable for installations using gas, oil or solid fuel. A few seconds after it is switched on, it automatically reminds the user to push a button to select the desired fuel. The F.E.M. is then calibrated to the fuel selected.

A sample of the flue gas is drawn through the detachable, stainless steel probe, by a small but powerful electric pump. Positive or negative flue gas pressures, within reasonable limits, will therefore not affect the sampling process. Temperature is measured within the flue itself. The sample gas is cooled in the probe, cleaned and dried by means of an easily replaceable filter before it is presented to the oxygen sensor. The microprocessor program ensures that stable readings are obtained, for maximum accuracy and reliability.

When the right fuel has been selected, the probe is inserted into the stack sampling hole and the OPERATE button is pressed. When sampling is completed (normally within one minute), a light and beeper tells the user that the F.E.M. has done its work.

Readings of efficiency, temperature and oxygen are retained in a memory and displayed on the large high brightness digital readout by pressing the DISPLAY SELECT button. The information is retained in the memory until the instrument is switched off or a further sampling operation is initiated.

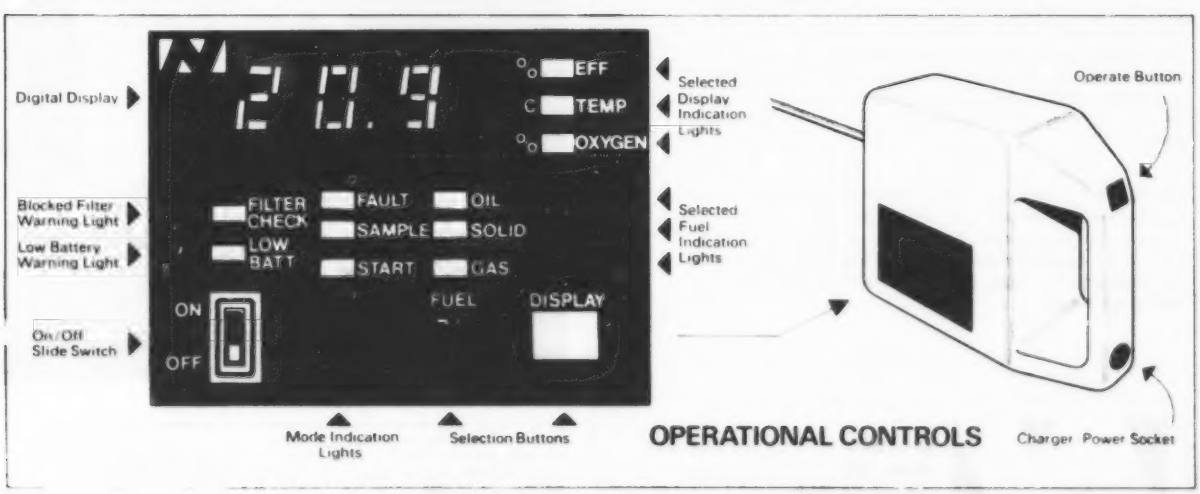
To make the operation of the F.E.M. even simpler, we have provided three warning lights, automatically indicating:

The filter needs changing.

The oxygen sensor needs replacing.

The internal Ni-Cad batteries are discharged.

A battery charger is provided. If necessary, the F.E.M. may be operated on the battery charger.




OPERATIONAL CONTROLS

***The F.E.M. is supplied in its own heavy duty carrying case complete with charger, spare filter and a comprehensive Operators Manual specially produced in close collaboration with the National Industrial Fuel Efficiency Service (NIFES).***

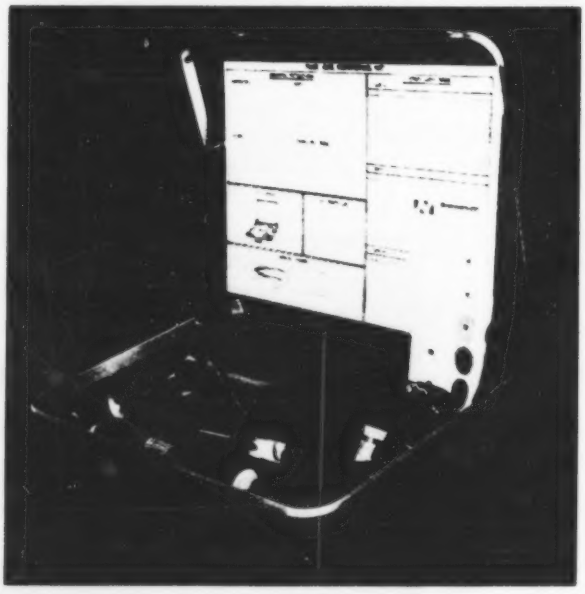
We have been engaged exclusively since 1973 in the field of monitoring and analyzing of gaseous mixtures. We manufacture a wide range of portable and fixed equipment for the measurement and detection of flammable gases, oxygen and toxic gases.

The F.E.M. was developed in a joint venture with the National Research Development Corporation, following a previous successful joint venture with NRDC in the field of automatic monitors for flammable gases.

**We have a basic business philosophy**

*We are not here to please ourselves, we are here to please our customer. This applies not only to products, but also to service, not only to technical design and quality, but also to price.*

The Neotronics (Energy Conservation) range includes fixed, custom engineered flue gas/oxygen monitoring systems and a trolley mounted system suitable for extended monitoring of stacks, yet easily moved from one installation to another. We also offer the easily portable OTOX 92 Stack Loss Measurement Kit.



**Neotronics of North America Inc.**
PO Box 129
Jefferson, GA 30549
Phone: 404-367-5124 Telex: 8107543981

In the interest of continued product improvement, we reserve the right to change design features without prior notice.
Pat. Nos. 8034110; 1474700; 1497657; 50583/75 (JAP); P2518354.4 (D); 147734; 4020480 (US). Pat. applied for: 51880/77; 78.34671 (F); P2853430.7 (D); 966.575 (US); 79.17380.
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